NOV 8 1923

Volume VII Number 5

BULLETIN

of the

American Association *of* Petroleum Geologists

SEPTEMBER-OCTOBER
1923

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EDITOR

PUBLISHED BY THE ASSOCIATION
CHICAGO, ILLINOIS

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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

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THE NATIONAL RESEARCH COUNCIL AND OIL GEOLOGY

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The purpose of this paper is to tell the American Association just what the Research Council is, how it functions, and how the Council and the American Association of Petroleum Geologists may work together to make oil geology more accurate, precise, and effective than it now is.

According to the report on the organization and members of the National Research Council, published in 1923, "The National Research Council is a co-operative organization of the scientific men of America. Its members include, however, not only scientific and technical men but also business men interested in engineering and industry." It was organized under the congressional charter of the National Academy of Sciences at the request of the president of the United States, expressed in an executive order May 11, 1918, which outlined the duties of the Council as follows:

1. In general, to stimulate research in the mathematical, physical, and biological sciences, and in the application of these sciences to engineering, agriculture, medicine, and other useful arts, with the object of increasing knowledge, of strengthening the national defense, and of contributing in other ways to the public welfare.

2. To survey the larger possibilities of science, to formulate comprehensive projects of research, and to develop effective means of utilizing the scientific and technical resources of the country for dealing with these projects.

3. To promote co-operation in research, at home and abroad, in order to secure concentration of effort, minimize duplication, and stimulate progress;

but in all co-operative undertakings to give encouragement to individual initiative, as fundamentally important to the advancement of science.

4. To serve as a means of bringing American and foreign investigators into active co-operation with the scientific and technical services of the war and navy departments, and with those of the civil branches of the government.

5. To direct the attention of scientific and technical investigators to the present importance of military and industrial problems in connection with the war, and to aid in the solution of these problems by organizing specific researches.

6. To gather and collate scientific and technical information at home and abroad, in co-operation with governmental and other agencies, and to render such information available to duly accredited persons.

During the war the National Research Council was financed, in part, by the government, but now the government has no connection with it except that members are appointed to represent certain governmental departments. In one or two divisions of the Research Council these departmental representatives form a majority, as in the Division of Federal Relations, but in most of the divisions they are a small minority. In the divisions of Physical Sciences and of Chemistry, in both of which the American Association of Petroleum Geologists should have keen interest, the government is not represented, and in the Division of Geology and Geography the government has but a single representative. Funds for financing the administrative work of the Council come from an endowment of $5,000,000, given by the Carnegie Corporation of New York. Funds for the Council's share in the cost of the new building for the National Academy of Sciences were secured from a number of independent sources.

The membership of the Council in its divisions consists of representatives officially designated by the leading scientific and technical societies of national scope, representatives of other particular research organizations, representatives of the government, and members at large chosen by the divisions.[1]

There has been much misconception concerning the activities and functions of the Research Council. It is not a laboratory where researches are carried forward. Neither is it a repository of funds to be used in financing research. It has almost no money of its own that may be spent in research work. Its work is to stimulate,

[1] National Research Council, Organization and Members, 1922–1923.

to effect co-operation, to secure financial support for researches, and to co-ordinate scientific attack on research problems.

I do not believe that any petroleum geologist of breadth and experience will deny that research is badly needed in his branch of geology. All too often the conclusions on which most reliance is placed are actually founded on assumption or theory rather than on demonstrated fact. They must be, for comparatively few of the important fundamental facts of oil geology have been demonstrated. For example, it is generally conceded that oil is derived from organic matter, and a few oil-yielding organisms have been isolated, but no one knows just what organisms yielded the oil in any one of the world's great oil fields. The processes by which the original organic matter was converted into petroleum remain to be demonstrated.

Shale is thought to be the mother or source bed of oil in most oil fields, but even if this assumption is accepted without definite proof being offered, the movement of the oil from the shale into the oil sand remains to be explained. Explanations have been advanced, but demonstration that these explanations are correct remains for the future. After the oil gets into the oil sand it migrates. This is known through observation, supported by laboratory experiment. It is not known, however, how far it will move; how fast it will move; what forces will interrupt the movement; what the direction of movement will be under many of the conditions that are known to exist in oil-yielding regions; what influence different rock compositions and textures have upon movement of oil; what control is exerted by temperature, pressure, viscosity of the oil; and many other factors. It is known that oil in nature is almost invariably in contact with water, but the effects of waters of different compositions on the composition, migration and accumulation of petroleum are unsolved mysteries. These examples might be multiplied almost indefinitely. Chemistry, physics, mathematics, geologic theory, have contributed but a fraction of what they must if the greatest measure of success is to be achieved.

Even application of theories regarded as so well established that they may be regarded as principles is halting and uncertain because of underdeveloped technique. Consider the occurrence of oil in

anticlines. Observation has proved that oil is more likely to occur under anticlines than to occur associated with any other type of fold or in flat-lying strata. But parts of most oil-yielding anticlines are barren, and it is only recently that geologists and operators have begun to realize that the failure of a test well, or even of several tests, drilled through the possible oil-yielding beds of an anticline does not necessarily condemn the structure. It is possible that the oil may be perched on one side or another of the fold, may choose one end at the expense of the rest of the structure, may be low on the flank instead of high on the crest, or may otherwise depart from the close relation between folding and the relative specific gravities of gas, oil, and water demanded by the anticlinal theory.

The increasing use of the fixed carbon content of coals as an indicator of the possibilities of oil in a region furnishes another example. David White demonstrated that thrust-pressure of regional extent would result in loss of volatile matter from the coals of the region affected, with consequent increase in the percentage of fixed carbon, and that these same forces would tend to destroy oil, leaving nothing but gas, or, if metamorphism progressed far enough, would leave neither oil nor gas. However oil geologists have not progressed beyond the point reached in 1915 by the originator of the theory. They are still dependent upon coal to serve as an indicator of the degree of metamorphism, and recommendations for drilling in most coalless areas must depend upon guess or inference rather than on determined fact, despite the fact that few prospective oil fields are without beds rich in carbonaceous matter, which should show the effects of metamorphism just as coal does, and which should prove as valuable to the oil geologist as coal is, once a method has been evolved to detect and calibrate those effects.

Both theory and technique may be perfected through research. The need for this research is urgent. Time is short and the demand for more petroleum than the known fields can yield will come before any study, inaugurated at the present time, will supply the knowledge that will let the oil geologists meet that demand with adequate new discoveries. It is therefore imperative that no time be lost repeating work on problems that already have been satisfactorily

solved. This means that they must know what research work on problems of oil geology and on related problems has been done, and what work is in progress. Without this knoweldge it will not be possible to plan wisely for future work. It must also be recognized that effectiveness, speed, and wide application of results of research can best be obtained when a number of workers co-operate. One man may supply the initial idea. Another may be so situated that he has both time and facilities for developing the idea. A third may suggest a number of possible applications of the work. A fourth may be able to furnish the raw materials for experimentation. The lone worker is handicapped, even if his theories are absolutely sound and if he has leisure for work and thought and all essential laboratory equipment.

The organizations that are fitted, by purpose and by character of membership, to bring about the highest degree of co-operation between research workers who are studying problems that bear on oil geology and the geologists who must prove the accuracy and adequacy of those studies are the National Research Council and the American Association of Petroleum Geologists. The functions of the National Research Council should be to:

1. Learn, in so far as possible, what researches are being carried on by workers in colleges, universities, research foundations, and federal and state bureaus, and by scientists outside such institutions or organizations.

2. Inform the workers on any problem of other work that has been or is being done on that problem.

3. Acquaint the petroleum geologists with projects under way or that recently have been completed; and with the research workers who are now engaged on specific projects, or who are ready to undertake studies that bear on petroleum geology.

4. Bring research problems to the attention of men or organizations capable of handling them.

5. Suggest broadening the scope of researches under way which, although not originally planned to bear on problems of oil geology, can be made to have such a bearing without affecting adversely the original plan.

6. Stimulate interest in research specifically designed to solve problems of petroleum geology.

7. Stimulate interest in petroleum geology in colleges and universities, and encourage organization of courses in such institutions to give students the best possible training to fit them to contribute to the science of oil geology.

The functions of the American Association of Petroleum Geologists should be to:

1. Manifest an active interest in research. This interest should be demonstrated by action taken by the organization as a body, as well as through the activities of individual members. The stimulation and advancement of research in petroleum geology should be pushed, both officially and unofficially, with the utmost vigor.

2. Formulate research problems to be submitted through the National Research Council to organizations or individuals equipped to study them.

3. Support researches by manifesting a live interest in them, by sending to their representative on the Research Council suggestions regarding possible applications or methods of attack, and by supplying materials such as well records, drill cuttings or cores, analyses, samples, etc., to the research workers.

4. Supply material for study by students engaged either in research or in general training for petroleum geology.

5. Provide for the funding of particularly important projects through the influence of either the Association or of members of the Association, or individuals or organizations able to supply the needed funds and who, logically, should be interested in and should profit from the undertaking.

The National Research Council has begun its part of this much-needed co-operative work by making a canvass of colleges and universities in the United States and Canada to determine what work is in progress on problems that have a bearing on petroleum geology. As a result, the writer, who represents the American Association of Petroleum Geologists on the Research Council, has been able to list some seventeen institutions that are carrying on research which has a direct bearing on problems of petroleum geology, and twelve others where researches that have an indirect bearing on petroleum geology are in progress, while fourteen more have expressed their sympathy with the campaign to advance research in petroleum geology and have signified readiness to assist in any way possible. The next step in this co-operative work must be taken by the petroleum geologists. In their turn they should send to the Committee on Studies in Petroleum Geology, of the Research Council, data regarding researches in progress, ideas, or outlines for researches that could advantageously be undertaken, and expressions of willingness to co-operate, with statements of just what form that co-operation may take.

PECULIAR PHASES OF OIL SATURATION IN CERTAIN SANDSTONES

GLEN M. RUBY
Denver, Colorado

The presence of oil in sandstones of Tertiary age in the Rocky Mountain region has been known for many years and in a few places considerable quantities of oil have been recovered. Wherever producing wells have been drilled there is strong evidence that the oil has come from underlying petroliferous shales of older, oil-bearing formations in contact with the sands, or faulting has permitted vertical migration to the fresh-water sands.

During the last three years there has been much speculation concerning the origin of the oil found in the Wasatch and lower Green River formations (Tertiary), of Utah, Colorado, and Wyoming. Several wells have been drilled in the Uinta Basin in Utah and in western Colorado without success and inasmuch as structural conditions in most cases were favorable and the objective sands showed oil saturation on nearby outcrops, the failure to find oil has been puzzling.

The lower portion of the Green River formation which is devoid of the "oil shales" contains several sandstones which show remarkable saturation in many places. Also, some of the upper Wasatch sands show saturation in a few places but by far the most prominent beds are those of the Green River. This saturation can be found almost entirely around the Uinta Mountains and, also, along the Grand Hogback in northwestern Colorado. At one place in the Uinta Basin, near Vernal, a conglomerate in the Uinta formation, several thousand feet above the base of the Green River, shows saturation to such an extent that it has been quarried and used for pavement in the town of Vernal.

North of the Book Cliffs, along the outcrop of the Green River sands the saturation is most prominent. The outcrop has such

extent and the sands appear so continuous that it was rather to be expected that many recommendations for drilling would be made. However, it appears that in most cases only brief notice was taken of the sand. Saturation was noted and probably accounted for in the regular manner, it being assumed that since the Green River formation contained oil shales, the sands had acquired the oil from this source, although the oil shales lie several hundred feet above the sand series which is associated with practically barren shales.

The writer's attention was first called to this saturation in Tertiary sands in Utah by the so-called "seep" previously mentioned near Vernal. During the late fall of 1916 this area was examined for its oil possibilities in the hope of finding anticlinal structure near the Vernal "seep." During this first examination the peculiar occurrence of the oil in the sandstone conglomerate was noted and certain phenomena could not then be accounted for. It was puzzling to find cavities in a conglomerate filled with asphaltum in which not a sand grain could be found. Inasmuch as the conglomerate contained much fine sand in proportion to pebbles, and appeared to contain no limestone breccia or pebbles of any consequence, the existence of cavities which could be filled with migratory oil was inexplicable. There apparently were no constituents of the conglomerate subject to solution whereby cavities could originate.

Later studies which included much more territory and in which the Green River "oil sands" were examined in detail formed the basis for a hypothesis as to the origin of these "oil cavities." This hypothesis was based primarily on the concurrent deposition of sand and oil, and subsequent investigation has shown it to be applicable to these formations. It is not claimed that all oil saturation in Rocky Mountain Tertiary deposits can be thus explained, but it is held by the writer that practically all saturation of the lower Green River sandy series has this origin. In support of this statement the following data are offered:

The material constituting the formations was the result of erosion of domal land masses still subject to upwarping movements. This same orogenic folding was likewise responsible for the retention of the Tertiary water-bodies. Older formations, especially Upper Cretaceous and Pennsylvanian, which were involved in the folding

are known to be oil bearing in this region and some of the oil undoubtedly migrated into these geanticlines and was permitted to escape by continued erosion. In many of these domal areas erosion progressed rapidly and all sedimentaries were removed so that later Tertiary beds rest unconformably on the granites.

Surface drainage from the surrounding land transported clastic material for the Tertiary beds. Streams from areas of doming and oil accumulation must have at times carried variable amounts of oil, depending on the size of the reservoir tapped by erosion or leakage to the surface permitted by faulting. It cannot be disputed that large quantities of oil were transported by surface drainage into the Tertiary lakes, where this drainage was off a doming land mass involving oil-bearing formations subject to erosion.

A careful examination of present-day streams in which oil is escaping will explain the occurrence of oil-filled cavities in a sandstone or conglomerate. Many such streams exist in the western United States and simliar conditions may be found in streams flowing through oil fields and tank farms where basic sediment is allowed to escape into surface drainage. There are several oil seepages along Tow Creek, in northwestern Colorado, and it was along this stream that "oil rolls" were first observed by the writer.

Fresh oil escaping from this seepage floats for a time on the water and as the more volatile constituents are lost by evaporation the mass sinks and is rolled along by the current. It assumes a spherical form or becomes a short cylinder, depending upon stream action. If entrapped in an eddy it soon rolls into a perfect sphere but if rolled steadily forward by the current it becomes cylindrical. It was noted that farther from the seeps these rolls became more viscous and some several miles below the source, were found to have the consistency of damp clay. Observations made over a period of three years showed the stream bed to be practically free from "oil rolls" after a flood, while during the period of steady flow every "hole" in the creek was practically floored with oil.

This oil, being carried along with sand and clay, must ultimately be deposited with it and the manner of its deposition depends upon the manner and amount of the oil escaping into the stream and the distance it must be transported.

Figure 1 shows that small amounts of oil escaped into contributory drainage and formed into balls and rolls by stream action. During floods the stream was scoured out and, depending on the strength of the current, variable amounts of viscid oil were deposited with the sand and gravel. A close inspection of the illustration will show breccia and large gravel which are usually transported by high water in steep streams. Many of these "oil rolls" exceed one-fourth inch in diameter and since they were plastic at time of deposition they conform to the shape of the cavity which was determined by the harder constituents of the conglomerate. In the same stratum from which this sample was taken oil rolls an

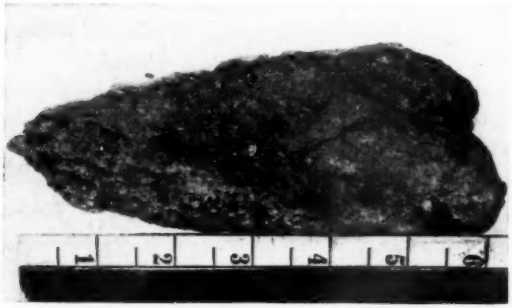

FIG. 1

inch in diameter were observed, but due to weathering they could not be readily preserved so as to withstand the difficult transportation of the collection.

Figure 2 shows two samples which likewise indicate a nearby origin for the oil and sands. In the larger specimen are two solidified oil rolls having over a half-inch minimum diameter. The upper "roll" shows a coal-like fracture and contains no sand or clay particles. Small pieces of it are readily soluble in chloroform. The lower "roll" has a conchoidal fracture, due probably to the clay particles it contains. It appears to have been rolled by muddy water and the inclusion of clay renders it somewhat less soluble in chloroform. This roll was apparently hardened by the clay

before deposition as it retains its cylindrical form and shows less distortion from pressure than the roll containing no clay.

Samples taken in this locality but where they were not subject to weathering show the oil rolls to be plastic. At a few points "assessment pits" and entries along the bed had been driven by prospectors, and in these it was possible to recover sandstone practically free from the effects of weather. In such samples the oil was still soft and some of the sand was unconsolidated, being held together only by the included oil.

The smaller specimen in Figure 2 shows oil rolls imbedded in micaceous sandstone. The entire stratum from which this was

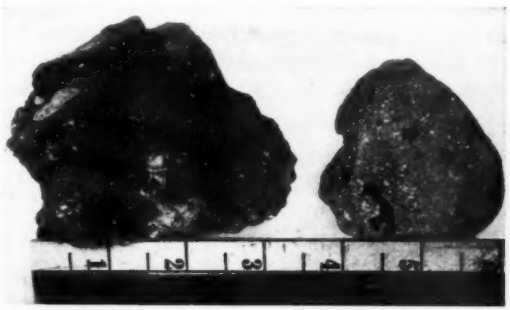

FIG. 2

taken shows variable degrees of saturation, with odd-shaped oil rolls imbedded in it. Where the sandstone is fine grained, so that large particles do not influence the shape of the oil rolls, they are found to be flattened by vertical pressure. The degree of flatness seems to be determined by the texture of the sand and the viscosity of the rolls at time of deposition.

Where oil has escaped in large quantities, as might be expected when erosion permitted the first burst of oil to escape from some reservoir, there would be a constant flow down the stream and into the lake or sea. If this oil should become sufficiently heavy to sink in the stream it would still flow into the sea and be spread out in much the same manner as other sediments. It would be

closely associated with the sediments in which it originated and which came into the sea as worked-over material in the same drainage. It would also be more or less mixed with these sediments, depending upon the relative amounts of oil, water, and sediment that the stream carried. On the other hand, if it floated out onto the surface of the lake or sea its final destination would depend upon currents and the direction of prevailing winds. In this manner, a sheet of oil or asphaltum might be deposited in clays or fine sands and not associated with the sediments carried by the stream which also carried the oil.

The writer knows of only one deposit of oil as a solid body interbedded in sediments, in the United States. This is found near the north end of Great Salt Lake, where at depths of a hundred feet and more, thick, viscous oil has been found in sheets. It is not in a sandstone but occurs in much the same manner as a seam of coal. Several of these "oil beds" have been found by drilling and digging wells and their nature is such that their presence may be explained by assuming the oil came into the lake as a sediment.

Oil-bearing formations were involved in the territory occupied by the Wasatch Range, east of Great Salt Lake, and this oil came in, either in the form of basic sediment in a stream emptying near present location, or it floated from another quarter to this location. Needless to say, drilling for commercial oil wells under such conditions cannot be destined for success.

An occurrence somewhat similar to that in Great Salt Lake is found in the Province of Angola, Portuguese West Africa, where the solidified oil has been mined for fuel and classed by English geologists as "oil coal." Dr. Arthur Holmes has ascribed for it an origin similar to coal, although chemical and physical analyses show it to be essentially petroleum. In regard to this deposit, the writer has had considerable correspondence with Mr. Harry L. Baldwin, a geologist who spent three years in this district, and he has, also, gained additional information from a Portuguese bulletin[1] in which the "oil coals" are described. A brief description

[1] J. Bacellar Bebiano, Chief Engineer of the Department of Mines, "A Descriptive Catalog of a Collection of Minerals Sent to the London International Exhibition, Together with Notes on the Mining Prospects of the Province of Angola," published by the Province of Angola.

of their nature and occurrence is given here since the origin is probably sedimentary.

This sedimentary oil is termed "oil coal" and also "Libollite," from its occurrence in the district of Libolo. Its age is supposed to be Cretaceous and probably older than the Cenomanian beds. The "oil coal" strata are interbedded in sandstones and conglomerates which rest unconformably on the Archean complex. There is no indication of the presence of shales or other sediments in sufficient amount to which the genesis of this oil can be ascribed. The following excerpt describes one of the strata of "oil coals."

> This asphaltic deposit is found bearing the following characteristics: (*a*) Asphaltic calcareous sandstone forming the "roof" of the deposit, its thickness exceeding two meters. (*b*) Asphaltic material, commonly known as "coal" with thickness varying from 0.5 to 1.5 meters. (*c*) Argillaceous sandstones impregnated with asphalt, closely resembling the bituminous shales of Scotland and forming the floor of the deposit. Its thickness exceeds 0.5 meters though the general thickness is unknown. There is, so to say, no differentiation between the "coal" seam, the hanging and foot wall, there being a gradual transition from the "coal" product into sandstone and asphaltic shale.

Nearly all analyses show an ash content in excess of 20 per cent. One sample shows nearly 3 per cent sand in the "coal." Considering these circumstances, it would seem that the "asphaltic deposit" could well have been in the form of a flow into the local lake and the sands both above and below it could have received their saturation by capillary action. Mr. Baldwin states that the underlying "shale" is really a fine sand and not in any sense a true oil shale.

A brief description of the Calucala field and adjacent territory shows that the beds associated with the "oil coal" are unconformable on the Archean basement.

> The carboniferous asphalt field is found in a basin surrounded by phonolitic rocks, some appearing folded forming anticlines and synclines, owing to pressure action.
>
> Bed A. Asphaltic, argillaceous, calcareous, and micaceous sandstone often interfoliated by small veins and pockets of "coal," with average thickness of three meters.
>
> Bed B (lower bed). Asphaltic, calcareous, sandstone, containing garnet, feldspar and fragments of gneisses and schists, the thickness varying from five to fifteen meters. (Rests on Archean basement.)

The occurrence of the "coal" in bed A in veins and pockets, strongly suggests sedimentary deposition. In this bed there appears no logical, indigenous source for the oil.

The two following paragraphs quoted furnish a more comprehensive understanding of this peculiar occurrence.

> The asphaltic coal appearing as lenticular-like veins and pockets, without any well defined direction, follows the argillaceous, micaceous sandstone, same occurring sometimes converted into a sort of viscous bitumen.
>
> We may conclude from what has been explained above that there is a connection between the known oil field of Angola and these carboniferous asphaltic deposits. It appears we are in presence of oil migration; the loss of the more volatile gases was probably produced by phonolitic eruptions transforming the liquid asphaltic oil into a special asphalt, both the hanging and foot wall of the "coal" deposit being equally impregnated by asphaltic matter. It is proved by analysis that Angola "coals" are essentially oil-producing materials and accordingly the right classification would be "oil coals."

The foregoing conclusion shows an opinion at variance with the previously mentioned theory of Dr. Holmes that the oil coal has an origin somewhat similar to true coals. The behavior of the oil coal, which melts and runs through the grates when fired under a boiler, tends to prove its true asphaltic nature. While the conclusions reached suggest some connection between the oil coals and the true oil field, and further, mention a degree of metamorphism of the asphaltic deposits, the present writer believes this metamorphosis from asphalt to its present form is due, in most part, to oxidation from contact with the air while being transported from oil-bearing beds to its present site, and later, to contact with the water of these local lakes.

It is not probable that the oil coal was transformed *in situ* from an oil deposit to oil coals by phonolitic eruptions and dikes. This may have caused some local metamorphism, but had the effect been regional so as to produce the almost general and uniform change claimed for it, there would have been no resultant bed of asphalt, if we may judge by similar effects in regions subject to more detailed study. Finally, the writer is unable to conceive of a solid body of oil, existing as a liquid, and in an individual and intercalated stratum, having its origin within any of the associated beds. It would seem that a free body of oil whether found as liquid

or solid, or in intermediate stages, and interbedded in sandstones and conglomerates, or any other substance not subject to solution by percolating waters, or having natural cavities, must be classed as a sediment and given an extraneous origin.

If there is any truth in this hypothesis it would follow that mere oil saturation in a sandstone under favorable structural conditions would not insure a commercial well. If only the interstitial spaces are filled with oil and no unnatural, oil-filled cavities exist in the sand series, true petroleum may be expected where structure is favorable to accumulation. On the other hand, if the sand shows "oil rolls," or asphaltum or paraffin exists as sheets or lenses, this sand series will not be productive of oil and only viscous wax can be recovered and in very small amounts, unless there are true oil-forming formations closely associated with the sands.

This should be kept in mind, especially in drilling continental Tertiary formations of the Rocky Mountain region, where the source of the oil causing the saturation is problematical.

THE BURKETT-SEELEY POOL, GREENWOOD COUNTY, KANSAS

HARVE LOOMIS
Ardmore, Oklahoma

The Burkett-Seeley region of northern Greenwood County has been attracting more interest during the past few months than any other part of Kansas. The discovery well drilled by Fisher, Lauck, and Moore on the Seeley farm in SE¼ SW¼ NW¼ Sec. 5, T. 23 S., R. 11 E., was completed June 19, 1922, with an initial production of about 300 barrels. The Barrington Oil Company completed their No 1 on the Burkett farm, SW¼ NE¼ NW¼ Sec. 24, T. 23 S., R. 10 E., September 12, 1922, with an initial production of about 250 barrels. These wells have not caused excitement because of their size but because the oil is of very high gravity (average 40 Be). This makes the region very attractive.

The pool is located about fifteen miles north of Eureka, and lies on what has locally been called the "Madison trend." The remarkable straightness of the producing belt is one of its most striking features. However, at one place between the Thrall pool and this there is an offset of two miles. There is doubtless a reason for the straightness of this line.

SURFACE STRUCTURE

The surface structure of this region was not worked in detail by the writer though it is known that there are present a series of small irregularities from the normal northwest dip. These minor folds are terraces and noses, and ordinarily would not be considered attractive as features which might cause accumulation of oil or gas in the sub-surface strata.

There are noses in the northern part of sec. 24, T. 23 S., R. 10 E., in the southern part of sec. 7, T. 23 S., R. 11 E., and in sec. 5, T. 23 S., R. 11 E. Between these noses and south of the one in sec. 24 are synclines of minor size which would usually be considered as of little importance.

SUBSURFACE STRUCTURE

The subsurface structure conforms fairly closely to the surface structure. As will be noted on the accompanying map of the region (Fig. 1.), the producing sand was found high in sec. 5, T. 23 S., R. 11 E., and in the northern part of sec. 24, T. 23 S., R. 10 E. The

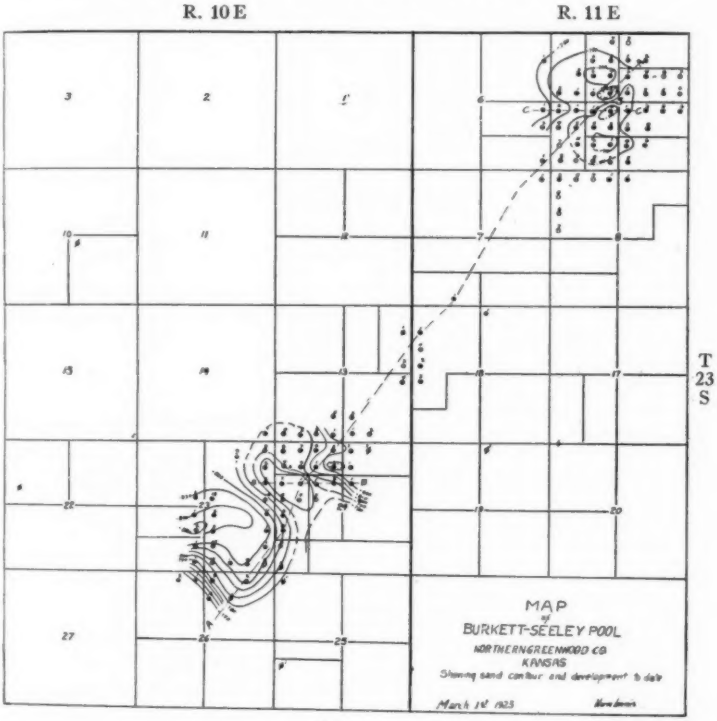

FIG. 1

contours of this map probably do not represent true structural conditions but the shape of the top of the producing sand. In other words, the east dip on the top of the sand is probably due to the pinching out—or at least a thinning—of the sand eastward. Any movement of these strata should be reflected in the surface rocks to some degree. The north and south dips on the top of the

sand are reflected but no east dip can be found in the surface rocks. Were the east dip on the top of the sand due to folding it should be apparent, to some extent at least, in the surface structure.

It will be noticed in profile *C–C* (Fig. 2), which shows the sand body in the Seeley region, that the sand is thinner in the Phillips

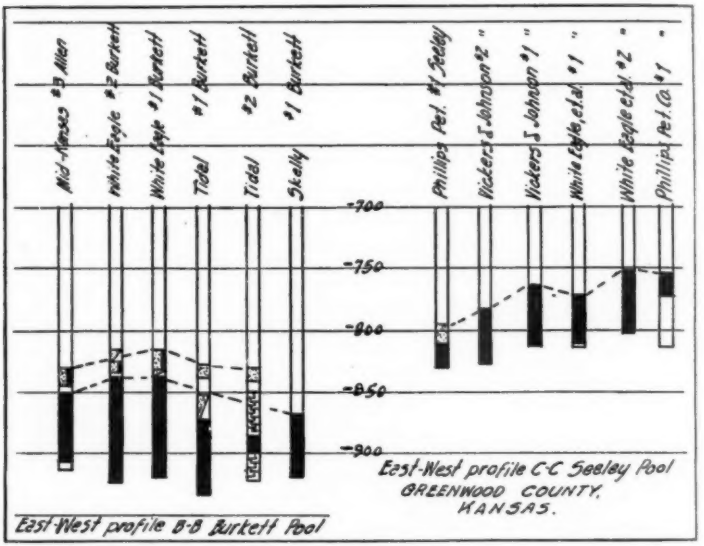

FIG. 2

Petroleum Co., Seeley No. 1 and in the White Eagle et al. No. 1, than in the White Eagle et al. Seeley No. 2. This in all probability indicates that the surface of the sand was more or less uneven when the overlying shale beds were deposited.

PRODUCING SAND

The producing sand of this region belongs no doubt to the Bartlesville horizon. A few of the edge wells have drilled through the sand and reached the Mississippi lime. Between the sand and the top of the lime is about 55 feet of blue shale with sandy and limy phases.

The sand has an average thickness of 58 feet and is usually very fine in texture. Some of the samples from the Burkett region are

extremely fine-grained. Hand samples obtained from a number of wells showed in nearly every case thin interbedded shale and fine sand. In a few cases very fine seams of coal were noted. In none of the samples was found positive proof of the origin of the sand. It could easily have been derived from the chert of the pre-Pennsylvanian rocks or possibly from the granite of the Nemaha Mountains. A gravel pit in northern Cowley county, Kansas, proves beyond doubt that a pure siliceous sand may be derived from the chert of the Permian limestones.

Sand probably came from the west in the very early Pennsylvanian time and, judging from the shape, this sand body was probably deposited as a sand bar a short distance off shore. The sand samples from two wells are unusually coarse, which may indicate that they are very close to the western edge of the pool. These two wells are the Pure No. 1 Mason (NE NE NW 26–23–10) and Derby et al. No. 1 Edwards (SW SE SW 7–23–11). A sample of the sand from the Rogers et al. No. 1 Allen (SW SW NW 18–23–11) would have been interesting in this respect but was not available. The log of this well shows 38 feet of sand while the Vickers and Johnson No. 1 Edwards, which is a direct offset on the west, reported no sand at this horizon.

There is a question as to whether the producing sand in the Burkett pool is the same as that in the Seeley. As will be noted on profile *B–B* a sand 10 to 15 feet in thickness occurs a few feet above the principal pay sand. This sand often shows some oil and gas and in a few wells was considered a part of the main pay and shot with it. The shale interval between these two sands is 3 to 18 feet. In one well on the Seeley farm, Fisher, Lauck and Moore No. 4 (NW SW SE 5–23–11) pay was found from 1,919 to 1,962 feet, with a shale break from 1,962 to 1,968, then pay sand from 1,968 to 1,992. This indicates that there is a possibility that the upper sand of the Burkett region is better developed in the Seeley region, and that the true Burkett sand is practically untested in the Seeley region. The Phillips Petroleum Company failed to find a lower sand in their well only a quarter of a mile north of the Fisher, Lauck, and Moore well. In the profile *A–A* (Fig. 3), the producing sand of the Seeley was considered the same as the producing sand of the Burkett.

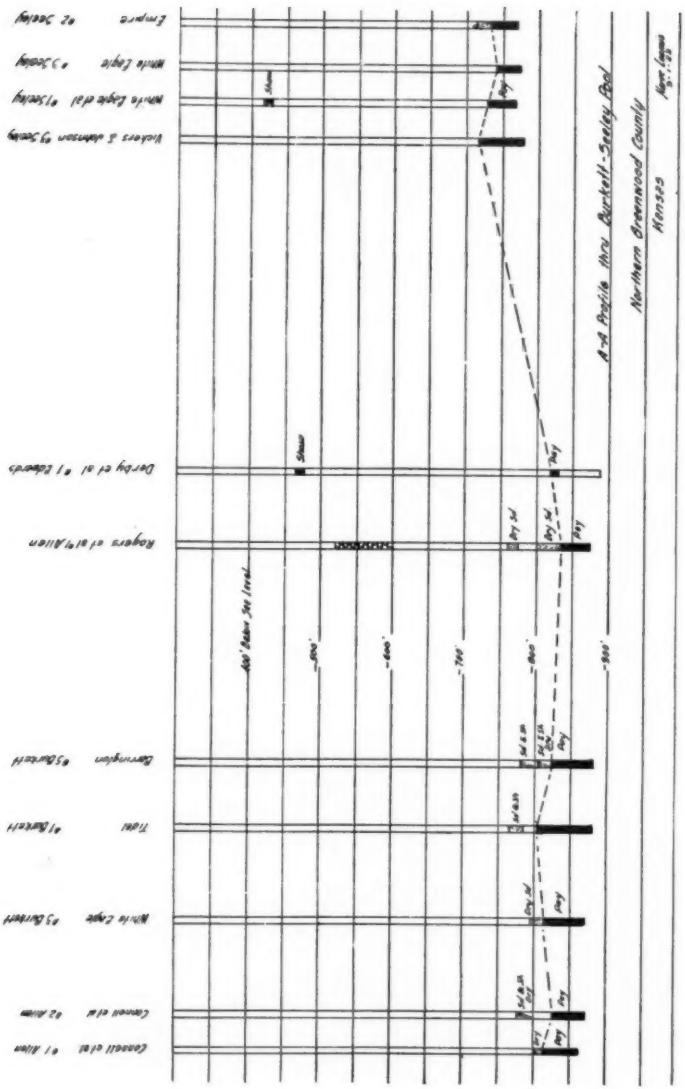
A-A Profile thru Burkett-Seeley Pool
Northern Greenwood County
Kansas
Mont. Equal
Connell et al '61 Allen
Cannon et al '62 Allen
White Eagle '53 Seeley
Tidal '61 Burkett
Barrington '53 Burkett
Rogers et al '71 Allen
Derby et al '61 Edwards
Vickers & Johnson '73 Seeley
White Eagle et al '73 Seeley
White Eagle '53 Seeley
Empire '62 Seeley

FIG. 3

PRODUCTION

None of the leases in this pool are sufficiently old to permit accurate determination of the rate of decline. The few wells on which first hand information was obtainable by the writer showed that the initial production figure, as is usually the case, was reported much too high. Usually the wells fill up 1,000 to 1,800 feet when they are drilled in, then are shot with from 40 to 120 quarts the following day. After the shot the wells are put on the swab and the amount of oil made in the first 24 hours of swabbing is reported as the initial production. The average reported initial production for the wells in this pool is above 250 barrels, while the figure should really be closer to 100 barrels. The actual pipeline runs from the field for February showed an average in the Seeley region of 79 barrels per well per day, while in the Burkett it was only 64 barrels. The decline will probably be rather slow as most of the fields in this part of the state which produce from the same sand horizon have held up remarkably well. The oil is of high gravity, which makes it possible to operate a lease until the production per well is quite small.

FIG. 3

None of the wells of this pool flow and most of them have to be shot fairly heavily before they make much oil. Each well makes enough gas, however, to run a gas engine and all wells are pumped from the beam on a unit system. Two companies are planning to install gasoline plants to take care of any surplus gas which the wells may make.

CONCLUSION

The accumulation in the Burkett-Seeley field is not dependent entirely on the local structure.

It is not possible from geological evidence to determine with accuracy the location of similar pools in advance of development.

By a study of sand samples it may be possible to determine whether or not a given well is on the east or west side of the productive sand body.

The remarkably straight line of production northeast from the Sallyards field is a matter worthy of special note.

THE ORIGIN OF LIGHT OILS IN THE ROCKY MOUNTAIN REGION

W. H. GEIS
Casper, Wyoming

The oil fields of the Rocky Mountain region are divided into two great classes. Color, gasoline content, and the geological horizon from which the oil is produced are taken in preference to the more dependable specific gravity as a basis for classification. The dividing line between the light oil and the black oil horizons is tentatively placed at the base of the Lower Cretaceous. The state of Wyoming, as it produces the bulk of the oil, is given first place in the discussion while only the light oils, those produced from Cretaceous rocks, are considered in this paper.

It is essential, in order to determine the origin of the oils, that the character of the rocks be understood. The Cloverly formation, at the base of the Cretaceous, where typically developed, is largely composed of sandstones. The various members are distinguished from the top downward as Dakota sandstone, Fuson shale, and Lakota sandstone. The entire formation is of fresh water origin. It is widely distributed throughout the state, but varies considerably in lithology and thickness. At several localities the upper member is missing, while at one locality, near the town of Byron, the entire formation appears to have been removed by erosion prior to the deposition of the overlying Colorado shales.

Above the Cloverly formation are the Upper Cretaceous Colorado and Montana groups. Due to the preponderance of shale in these divisions they are usually referred to as the Colorado and Montana shales. Both groups are of marine origin and contain sandstone members of great importance as oil reservoirs. The Colorado group is subdivided into the Thermopolis shale at the base, above which in ascending order, are the Mowry, Frontier, Carlile, and Niobrara formations. The Montana group is marked at the base by the light gray Steele shale, which includes several

sandstone members. Above the Steele shale, in ascending order, are the Mesaverde, Fox Hills, or Lewis formations. Inasmuch as no commercial production of oil has been found in Wyoming

FIG. 1.—Map showing areal distribution of Mowry shale with relation to developed oil and gas fields.

in rocks stratigraphically above the Mesaverde formation, such younger rocks are excluded from this discussion.

Having in mind the general sequence of formations, we may now consider the particular members which are productive of oil. Naturally this leads to a study of the sandstone members. The Mesaverde formation is largely composed of sandstones interbedded with shales and coal. It is marked at the top by the Teapot sandstone and at the base by the Parkman sandstone which overlies the Steele shale. At approximately 1,000 feet above the base of the Steele is a prominent sandstone, the Shannon sand. Both above and below the Shannon but still within the Steele shale, there are found other sandy members which, apparently, are as persistent as the Shannon. One such member, about 400 feet above the base of the Steele, has been called the "Fish Tooth" sandstone at Salt Creek. There are also some non-persistent stray sands which are erratically distributed throughout the Steele shale.

The Niobrara formation contains few, if any, sandstone members. Throughout central Wyoming the upper Niobrara may grade into sandy shale, but no definite sandstones are reported, save on the G. P. dome in Carbon County, Wyoming, where a fairly porous sandstone apparently exists. Below the Niobrara, the Carlile formation, in central, southern, and western Wyoming, is entirely composed of black shale. In eastern Wyoming, especially in the Black Hills district, the Carlile contains thin sandstone members.

The Frontier formation, below the Carlile, is especially noteworthy because of the occurrence in it of several very distinct and conspicuous sandstones, which have become known as the Wall Creek sands. The number of sandstones may vary from one to twelve. The bulk of the light oil in Wyoming fields is produced from these sands.

The Mowry member of the Benton shale contains, in the Big Horn Basin at least, two distinct sandstones, known as the Kimball and Octh Louie. It is likewise sufficiently sandy in the Ferris oil field, Carbon County, Wyoming, to act as a reservoir sandstone. The Muddy or Newcastle sandstone is a very definite and widely distributed member of the Thermopolis and Graneros shale. The

sandstone members of the Cloverly formation have already been identified as the Dakota and Lakota.

In all, therefore, there are eleven distinct sandstone horizons distributed through the section of the Cretaceous rocks, which may under favorable conditions, act as reservoir rocks for oil. That all of these members are not productive of oil, or are productive only to a limited extent, is not considered to be due entirely to structural and drainage factors, but probably may also be due to the stratigraphic relationship of the reservoir rocks to the source beds of the oil.

If the oil fields of Wyoming are classified according to the productive sandstones, it is found, from the tabulation in Table I

TABLE I

SANDSTONES PRODUCTIVE IN THE WYOMING OIL FIELDS

Teapot	Shannon	Niobrara	Frontier	Mowry Shale	Muddy	Cloverly
			Show		Rock River	Rock River
			Byron		Byron	Byron
						Greybull
			Lamb	Lamb		
				Torchlight		
	Big Muddy		Big Muddy.			
			Ferris	Ferris		
			Lost Soldier			?
	Pilot Butte					
			Grass Creek			
	Shannon					
			Salt Creek			Salt Creek
			Lance Creek (?)		Lance Creek	
						Mule Creek
			Elk Basin			Elk Basin
					Osage	
						Mahoney
			Sand Draw			
Golden Eagle						
						Oregon Basin
			Buffalo Basin			
			Rock Springs			
			Hidden Dome			
			Murphy Dome			
			Lox Dome			
	Teapot	G. P. Dome	Teapot			
				Spring Valley		
				Labarge		
				Shoshone		
				Plunkett		

that one field is productive from the Mesaverde formation, four from the Shannon, one from the Niobrara, sixteen from the Frontier, four from the Muddy, seven from the Cloverly, and seven from the Mowry.

The writer has always considered that the origin of oil is a chemical problem and that the geologist should not be so interested in the question of *how* or *why* the oil originated, but rather *where* it originated. From the tabulation it is evident that the Frontier or Wall Creek sandstones are by far the most universally productive. It is probable that the potential daily production of the Wyoming light oil fields approximates 175,000 barrels per day, and of this total, 160,000 barrels, or 91 per cent, are derived from the Frontier sandstones. Therefore, although numerous fields produce from sandstones other than the Frontier, such production is of relatively minor importance. May we not then admit that, while several distinct origins may exist, the most competent is probably located near the Frontier sandstones. Perhaps, by a process of elimination, the *exact* position of this competent origin can be found.

There are, at most, only three probable hypotheses concerning the migration of an oil from its origin to the reservoir rocks: (1) it migrated upward from the source to the reservoir; (2) it migrated downward from the source to the reservoir; or (3) it originated within the reservoir. The writer considers that the migration, in the latter two cases cited, while possible, is probable only in exceptional cases such as in overturned folds, or on faulted anticlines such as the Cat Creek structure in Montana. Again he considers it unwise to presume that rocks which are deposited under such conditions as were the sandstones could furnish an origin for oil, and therefore assumes that the oil now found in the various sandstones, as listed, must have migrated from an origin below the sands.

In accounting for the accumulation of dry gas in the Mesaverde sandstones on the Golden Eagle dome in Wyoming, the first hypothesis presented is that the hydrocarbon product came from below. This would seem possible in view of the considerable thickness of carbonaceous shales associated with the sandstones. But the Parkman sandstone, at the base of the formation, has, where penetrated, been usually found to be water-bearing. This would seem to indicate at least that the hydrocarbon product originated above the Parkman sandstone and that it did not migrate downward. The author knows of no locality where oil or gas has been found in the true Parkman sandstone. Also this member is devoid

of oil seeps, which is significant, when we consider that the productive sands of Wyoming usually do show oil seeps, at least at some of the many outcrops.

Any oil or gas found in the Parkman would then, apparently, have to be derived from that portion of the Steele shale above the Shannon sandstone. This shale seems to be not very different from the shale below the Shannon, and the fact that the Parkman sandstone is dry would cast a doubt upon the value of the upper Steele shale as a source bed. The same conclusion might be reached, when we consider that about 400 feet above the Shannon there exists another sandstone member which has been found to yield water on several folds where the Shannon has produced oil. If the shales associated with this sandstone were sources of oil, it should accumulate in this sandstone or in the Parkman above.

The problem becomes decidedly more complex when we consider the four known cases of oil accumulation in the Shannon sandstone. It is impossible to identify the productive horizon at Pilot Butte, Wyoming, as the Shannon, but in the other three cases, namely at Shannon, Teapot, and Big Muddy, it seems evident that the oil has migrated from a considerable distance below. These fields are located on faulted anticlines and the records of wells show, especially at Salt Creek, Teapot, and Big Muddy, that production is often found in faulted zones in the shales below the Shannon sandstone, and above the Wall Creek sands. Along many of the faults in the Salt Creek field, especially on Sec. 36, T. 40. N., R. 79 W., there are oil seeps, while the calcite fault filling is saturated with bitumen. The production at Shannon is located against one of the major faults of the district.

From such evidence it would seem that some of the oil which accumulated in the Wall Creek sandstones has escaped along fault planes. In some cases, the migrating oil has reached the surface of the ground, but at Shannon and Teapot the oil apparently accumulated in the first porous medium encountered in its upward migration. Sometimes this medium was a porous shale, in which a slight accumulation occurred, but such pools have always been limited in area with the production growing less and less as the wells were drilled farther from the fault.

The Shannon sandstone has been tested on many structures in Wyoming, but the results usually have been disappointing save on those folds where escape for oil is possible from pools in sands below. We are therefore led to believe that the oil now found in the Shannon sandstone originated from the same source as did the Wall Creek oil and that it did not originate in the Steele shale. Therefore the Steele and its correlatives, the Cody and Pierre, may be eliminated as important original sources of oil, leaving only the Colorado shales as the possible source of supply for our largest pools.

Probably not all of the members of the Colorado group are of equal value as original sources of oil. Oil has been found within the Niobrara formation, only on the G. P. dome in Carbon County, Wyoming, where the Frontier sands are not productive. The main production from this district is found in the Frontier and Dakota sandstones at Little Lost Soldier, Wertz, and Mahoney fields, but in these cases the Niobrara is non-productive. No other commercial production has been found in the Niobrara formation although it has been tested on many Wyoming structures and therefore great doubt must be cast upon this particular formation as a competent source of oil.

Eliminating the Niobrara as a probable source, the next lower formation would be the Frontier. The Frontier sands are so frequently productive, and produce oil in such quantities, that it would appear that they are located in very close proximity to an extremely competent origin. It has been shown that the oil probably did not originate above the Frontier; it could, however, have originated either within the formation or in some formation below. Both of these possibilities will be considered.

The Frontier formation is largely composed of dark gray to black marine shale with interbedded thick sandstones. The separating shale masses appear to be quite similar in character and there is little reason for believing that one of these members constitutes a source and that another does not. In order to determine whether the Wall Creek oils may be indigenous to the Frontier formation, the results of drilling in various fields must be analyzed.

The geologic section, of the Frontier, at Salt Creek, as revealed by drilling, is as follows:

	Thickness Feet
First Wall Creek sandstone	125
Shale	260–280
Second Wall Creek sandstone	60
	445

It is probable that at least 200 feet of the dark shale below the Second Wall Creek belongs to the formation. Both of the Wall Creek members are productive of oil in the Salt Creek field but the lowermost, or Second Wall Creek, is by far the more important as it upholds wells of larger initial capacity and greater ultimate production than does the First sand. The oil pool in the First Wall Creek sand covers, roughly, 5,000 acres, while the pool in the Second sand covers some 20,000 acres. Irrespective of the fact that the First Wall Creek sandstone is approximately twice as thick as the Second, the average porosity of the Second sand exceeds that of the First, so that the oil content of the lower sandstone vastly exceeds that of the upper. This would seem to indicate that the most competent origin is located nearer to the Second than it is to the First sand.

It must also be remembered that the Salt Creek fold is very severely faulted and that oil has migrated, along the fault planes, to accumulate in the shales above. It may be that, in so far as the same faults penetrate both of the sandstones, the oil now found in the First Wall Creek sand has had a like history with the shales, and accordingly that it has migrated from the greater accumulation below.

The Frontier section, in the Grass Creek oil field, in most places contains about eight sandstone members. Of these the first, or uppermost is water-bearing. The second, third, fourth, and fifth produce gas near the top of the fold and oil on the flanks. The sixth, seventh, and eighth are universally oil-bearing and now uphold the main production of the field. At Elk Basin the First Frontier, or Wall Creek sandstone, contains only a limited amount

of oil while the Second Frontier, or lowermost sandstone, is the chief producer of the field. The same is true on the Arminto anticline where the First Wall Creek is water-bearing; the Second sand contains gas only, while the Third contains oil and gas in small quantities.

From these examples, to which may be added the Lost Soldier field, it appears that there is a gradation in production from the top of the Frontier formation toward the bottom, and that so far as oil is concerned the greatest accumulations are in the lowermost sandstones. Such facts lead to the conclusion that while the Frontier shales may be source beds to a limited extent, yet the oil found in the Upper Frontier sandstones may be accounted for by migration of one kind or another. Considering all of the facts so far presented it seems apparent that the light oils of Wyoming have originated in the lower portion of the Benton shales, that is, from within the shales below the Frontier formation. This shale body is divided into two formations, the Mowry and the Thermopolis. If these shales really are a source of oil, there should be certain distinguishing features which are not present in other "dry" shales.

The Mowry shale does contain productive sandstone members, as on the Lamb, Torchlight, Ferris, Shoshone, and Spring Valley anticlines. The Muddy sandstone, a member of the Thermopolis shale, is productive in many places where favorably folded. On those folds where the Wall Creek sandstones contain oil, the Muddy sandstone if present is likewise productive, as is also the Cloverly formation. The product in all cases is either gas or a light grade of oil, and yet immediately below the Cloverly formation the product found in the Morrison and Sundance formations is a heavy black crude. The evidence leads to the conclusion that the light oils of Wyoming originated in the Mowry and Thermopolis shales. If this be true, it should be substantiated by a study of the areal distribution of these shales relative to the distribution of the oil fields.

The Mowry shale, as well as the Thermopolis, is quite generally present in Wyoming; but in the other Rocky Mountain states the distribution is erratic, while in all of these states no commercial pools of light oil have ever been found in the sandstones of the

Colorado group in an area where the Mowry shale is missing from the geological section. More clearly to present this fact, a map has been prepared showing the areal distribution of the Mowry shale. No light oil fields have been found outside the area covered by this shale, although probably a hundred tests have been drilled on structurally favorable anticlines.

Consider, more specifically, the numerous tests which have been drilled in Utah, where the Mowry shale is missing. The Colorado group is present and contains sandstones, notably the Ferron, in the approximate stratigraphic position of the Wall Creek members of Wyoming. Certainly the Huntington, Woodside, and Caineville anticlines are favorable structurally, and have adequate reservoir sands buried at a sufficient depth, and the fact that these structures are dry seems to be due only to the lack of a source of oil near the sands.

The Mowry shale is missing from the Cretaceous area of western Kansas, where several unsuccessful wells have been completed. Some of the wells drilled have found reservoir sands within the Colorado group but it is impossible for any fold to contain oil when there is no source material from which the oil could originate.

In Colorado the only oil fields developed have been within the Mowry area. It is important to note, however, that the beginning of oil showings and the development of gas in wells, is coincident with the Mowry contact, and that these showings are not found outside of the Mowry area.

Montana furnishes the best examples of the relationship of the Mowry shale to oil production. The map shows the Mowry to be widely distributed, yet so great is the variation in lithology that often the investigator is puzzled to identify the formation. Many times the shale is said to be present when in fact it is not the Mowry but a shale only slightly similar. So far as the writer has been able to determine, the typical Mowry exists only in central and eastern Montana, and is entirely lacking from the Lake Basin and Musselshell districts. However, a notable development of the Mowry exists in the region from which the Cat Creek fold would drain oil. The Cat Creek anticline is no more favorable structurally than are many other anticlines in Montana, such as Shawmut, Big Elk,

Howard Coulee, Big Wall, and Woman's Pocket, all of which are in the Musselshell Valley. These folds have been proved to be dry although there are adequate sandstones within the Colorado shales. The same is true with the structures of the Lake Basin district where Big Coulee, Hailstone, Duck Creek, Joliet, and Broadview have been tested and have been found dry. All of the above structures are located either within or adjacent to a drainage area where the Mowry shale was never deposited and this fact may account for their failure to produce oil. On the extreme eastern edge of the Musselshell district the first outcrops of Mowry shale are found on the Devil's Basin anticline. The formation thickens to the north and east until it measures eighty feet near Cat Creek. As the thickening increases the oil and gas showings proportionally increase; the Ohio Oil Company's well on the Ragged Point anticline had showings of oil and gas in the Colorado sands. This structure is underlain by thirty feet (estimated) of Mowry shale. The same character of evidence can be found in northern Montana along the Canadian border and southward. The Mowry shale is present but often resembles but little the true Mowry of Wyoming. Several test wells have been drilled, notably at Willow Creek, Clear Creek, and on the Havre anticlines and as yet no commercial production has been developed.

The Mowry shale has been given the most consideration in the above discussion although the capacity of the Thermopolis shale to act as an oil source is admitted. The Thermopolis shale is not always well developed in Montana and often the Mowry may rest directly upon the Kootenai, or if separated from it, the separating shales do not resemble the true Thermopolis shale.

From the foregoing observations the writer concludes: (1) that the light oils are produced from sandstones adjacent to or from members of the Colorado shale group; (2) that the sandstones closest to the Mowry shale are the most prolific producers and the most universally productive; (3) that no oil fields have been discovered in the area not occupied by the Mowry shale; (4) that the light oils are found only in the sandstones above the Morrison formation and have no genetic relationship to the black oils found below the same formation; and (5) that the light oils of the province

can be directly traced to an origin within the Mowry and Thermopolis shales.

If such is the case, what are the features which distinguish an original source bed from one which is not a competent source, or in what respect is the Mowry shale, for example, different from other shale bodies?

The Mowry shale is quite similar, in general characteristics, at all of its outcrops in Wyoming, but varies in thickness from 100 feet in the east part of the state to 1,600 feet in the west, where it is known as the Aspen shale. In detail, however, the characteristics vary rather widely. Unweathered, the shale is dark brown to black but on weathering changes in color to a silver gray, or when the action has been prolonged even to white. The color change is confined solely to the surface of the rock, and apparently is due to the leaching of the soft argillaceous and carbonaceous matter leaving a protective coating of the siliceous and calcareous material. This coating, if examined, will be found to be composed largely of the remains of organisms, especially of diatoms and Foraminifera. In thin section the black color is seen to be due to particles of carbon, collected into definite areas or disseminated throughout the mass.

One of the diagnostic characteristics of the shale is the profusion of fish scales which occur in practically all specimens. The scales range in diameter from one-sixteenth to three-quarters of an inch and often completely cover the minute bedding planes of the shale, lending a brown color to the rock. Fish bones and the tracks of marine animals are also found. At several localities, especially near the Black Hills, volcanic ash forms a minor portion of the mass.

The Mowry shale is evidently truly organic and the conditions under which it was deposited may be interpreted. During the deposition of the shale there were constantly being added to the true sediments the remains of myriads of dead organisms. These organisms were retained in the consolidating rock and may, under distillation, have been converted into petroleum hydrocarbons. The products of the distillation would be retained in the rock or would escape in proportion to the retentive character of the surrounding shale. Some such process evidently existed, for even at the present date,

and often from the weathered specimens, it is possible to distil oil from the Mowry shale. Samples from central Wyoming to northern Montana have been tested, which produce from a trace to several gallons of oil per ton of shale.

The distinguishing feature of the Mowry shale may therefore be the organic content, and the fact that other shales, such as those of the Montana group, are not competent sources may be due to their lack of such constituents. There are many factors which may control the number and variety of organisms inhabiting a particular sea. Among these are temperature, depth, and the chemical character of the waters. The factors of deposition are also constantly changing so that it seems quite possible that a shale body may furnish an origin in one locality, and yet in another may lack the organic material which would eventually produce oil. Between such extremes where may be all gradations in the capacity of the shale to act as an oil source. Such is probably the case with both the Mowry and Thermopolis shales.

The writer considers that in an organic shale capable of affording an origin for oil the process of decomposition or distillation is a continuous one and may depend largely upon the nature and the severity of external forces affecting the shale mass. This would cause the various products of the distillation to be given off at different times—a sort of fractionation. The decomposition may have reached an advanced stage before the organisms are incorporated in the sediments; or again, the organisms might be covered immediately after death by the sediments. In either case it seems probable that the first products of the decomposition may escape, or that several of them may be lost while the balance are retained. The final mixture then, if petroleum, might have different characteristics dependent upon what part of the products of the decomposition were retained.

There seems to be, in Wyoming, a relationship between the gravity of the petroleum products found in the Wall Creek sands and the arenaceous phase of the Mowry shale. This phase may in turn be indicative of the porosity of the sediments at the time of deposition and proportional to the probable escape of the products

of decomposition. There are several well-known reasons why sandstones are not believed to yield indigenous oil; and a shale body which is being deposited near shore, and hence approaching to strand line conditions may lose, to some extent, its capacity to retain the products which would eventually have produced oil. It may be coincidence, but if such a relationship exists it should be evident when we analyze the conditions found in Wyoming oil fields.

The Wall Creek sands, in the Salt Creek field, produce oil in such quantities, and over such a large area, that the field must be located in a region where considerable oil was originated. The Mowry shale, just west of the field on the Tisdale anticline, is composed entirely of shale with a few beds of bentonite. It is 300 feet thick and considered a single lithological unit. The gravity of the oil at Salt Creek is 39 degrees Baumé. From exposures both west and south of the Big Muddy field we know the Mowry to be composed of 175 feet of shale. Big Muddy crude has a gravity of about 35 degrees B. On the flanks of the Black Hill uplift where the Mowry is exposed, near the town of Thornton, it is 150 feet thick, but included in this thickness is a volumetric content of sand, rather equally distributed through the formation equivalent to 30 per cent of the mass. The sandstones above the Mowry in this district are not exact equivalents of the Wall Creek members, but such sands as are present have been found to contain some oil at one locality or another. A grade of crude gasoline is found in the basal sandstone of the Carlile, at Thornton, though the production is small and uncommercial. This condition may be due to the failure of the Mowry as a competent origin. The Thermopolis shale is present, affording an origin for the oil now found in the Muddy sandstone at Osage and Lance Creek. In the Laramie Basin the Mowry is composed of sandy shale with a sand content perhaps greater than that of the Black Hill section, due to the development of true sandstones in a mass of sandy shale. The results are in accord with those of the Black Hill district; the Frontier sandstone, developed to a thickness of 30 feet, is generally dry in the Rock River district while the Muddy and Dakota sandstones below produce oil.

The best examples of the effect of a sandy origin on the character of the oil are found in the Big Horn Basin. In this district numerous folds have been tested, some of which produce oil, others gas, while a great many are devoid of either. The Mowry shale, composed of typical shale, in places grading to sandy shale and containing distinct sandstone members, varies in thickness from 150 to 400 feet over the basin. A section of the Mowry, taken from the logs of wells drilled on the Oregon Basin anticline, shows it to be 291 feet thick.

	Feet
Sandy shale	18
Sand	13
Bentonite	4
Black shale	80
Sand	27
Shale	16
Sand	10
Shale	36
Sand	5
Shale	77
Sand	5
	291

This section is composed of 70 feet of sandstone and 221 feet of shale. The proportion of sand to the entire section is 24 per cent.

On Shoshone River, the Mowry shale at the outcrop nearest to the Byron gas field, is 429 feet thick with a sand content equal to 20 per cent of the formation.

	Feet
Sandy shale	32
Shale gray	56
Sandstone	4
Bentonite	4
Shale gray	45
Bentonite	4
Shale	151
Sandstone	80
Shale	50
Sandstone	3
	429

As revealed in the log of the first deep test drilled at Grass Creek, the Mowry shale is 287 feet thick with about 33 feet of sandstone and a sand content of 12 per cent.

	Feet
Shale, with water, sandy	98
Shale	17
Sandy shale	23
Shale	35
Shale	17
Sandy shale with oil	10
Shale	87
	287

In the vicinity of the town of Basin the Mowry shale has a total thickness of 160 feet. It contains two sandstones having a thickness of 28 feet and furnishing a sand content equivalent to 17 per cent of the mass.

Tabulating the percentage of sandstone present in the Mowry shale in the various fields against the gravity of the oil obtained, a gradation appears to be apparent.

Field	Sand Content (In Per Cent)	Product	Gravity Baumé
Salt Creek	0	Oil	39
Grass Creek	12	Oil	43
Basin-Greybull	17	Oil	45
Byron	20	Oil and gas	50
Rock River	30+	Dry	.....

The percentage of sand in the Mowry formation seems to increase from 12 per cent at Grass Creek to 24 per cent at Oregon Basin, and again decreases eastward toward Bryon and Greybull. At Byron the sand constitutes 20 per cent of the formation and the product obtained is mostly gas with a small quantity of high gravity oil. What then would be a forecast of the product obtainable in the area adjoining Oregon Basin and north of Grass Creek? This area should probably show a sand content in the Mowry of 19 to 22 per cent, and we would say that the product derived would approximate that found at Byron. As a matter of fact, the Buffalo Basin anticline, within this area, produces great quantities of gas from the Wall Creek sandstones.

The Elk Basin anticline is located 18 miles northwest of the Byron gas field and a simple calculation indicates that the sand content of the Mowry at Elk Basin should be about 17 per cent. This would be the percentage obtained if the apparent decrease northward from Oregon Basin to Byron continues to Elk Basin; the decrease being approximately 1 per cent for every six miles. The product found at Elk Basin should then, on comparison with the Basin-Greybull district, be an oil of about 45 Baumé gravity. The oil found in the Frontier sands at Elk Basin has a gravity of 45.1 B.

The writer therefore concludes that all of the light oils of this region are genetically connected with the shales of the Colorado group; that the primary origin of the oils found in the Frontier sandstones is the Mowry shale; that the oils in other sandstones, such as the Muddy and Cloverly, originated from the Thermopolis shale; that in the event that the Mowry shale is missing, or fails as a source bed, no oil will be found in the Frontier formation, although if the Thermopolis shale is present, the lower sands may be productive; that by a study of the probable shale origin in a district it is possible in some degree to forecast the character of the hydrocarbon product obtainable. Finally it should be emphasized that for a number of reasons an anticline may be unproductive and of these the factor of origin is only one.

DISCUSSION

J. M. Douglas: In the Lost Soldier, Rock River, and Mule Creek oil fields in Wyoming and in the Cat Creek oil field in Montana the chief productive sands are below the source of the oil. It is noteworthy that in these fields the formations dip steeply—generally greater than 30 degrees at least on one side of the fold. Therefore, the oil can have migrated laterally and vertically into the sands which are stratigraphically below the source.

Walter English: Lack of presence of oil in the Mowry at the present time, even though it was the source of a large amount of oil, is paralleled by conditions in California. The Monterey shale, which is generally accepted as the source of most of the oil, yields in most places only a slight amount of oil or gas on distillation tests.

Junius Henderson: In the search for the origin of oil in various formations it is unfortunate that more work has not been done with the microscope. Assuming that the source of oil is organic, the total bulk of microscopic organ-

isms in the waters which deposited the sediments probably in most instances vastly exceeded that of macroscopic organisms. Some of the petroleum geologists are doing such work and others are intending to do so, but a great deal more should be done. Incidentally, in studying the thin sections for the detection of evidence of organic remains, the fact that the character of the grains of sand, etc., may throw much light on problems of sedimentation, as shown by profound investigations in recent years, should be kept constantly in mind.

W. E. WRATHER: Professor Henderson's remarks on the origin of oil coincide quite closely with the view expressed by Dr. Schuchert in a paper on Petroliferous Provinces, published in the *Proceedings of the A.I.M.M.E.*

In the Gulf Coast region of Texas and Louisiana, and also in the Mid-Continent oil fields, a great deal of highly interesting and instructive microscopic work is being done on well cuttings. The minute forms of life, invisible to the naked eye, are being studied and identified and in many cases are proving to establish horizon markers which could be identified in no other manner.

W. KRAMPERT: In the Lost Soldier field the principal production is from the Dakota, below the Mowry, which I concede to be the original source of the oil. The Wall Creek series contains oil though it is evident that the oil came from the Dakota through faults.

L. C. SNIDER: Regarding downward oil migration I may note that in the Mid-Continent fields downward migration is, I believe, a much more important factor in accumulation than it seems to be regarded by Mr. Geis for the Wyoming fields. This is particularly true for the deeper fields in Kansas, such as Eldorado and Augusta, Peabody and Florence.

F. F. HINTZE: In relation to the origin of the oil found in the Shannon sandstone at Salt Creek and Big Muddy fields, Wyoming, it seems unnecessarily far fetched to suppose that it came from the Mowry shales which lie below the Wall Creek sandstones. At Shannon, north of Salt Creek, oil is found on a faulted monocline, and in order for the oil to reach its present position, and come from the Mowry, it would have to migrate across two thick sandstone members of the Frontier formation and pass through nearly two thousand feet of strata, mostly shale. The Wall Creek sands carry water, which would also have to be penetrated. At Big Muddy a similar situation exists, except that the oil occurrences are due to lensing of the Shannon sand instead of faulting. Here it would be necessary to postulate enough fissures and faults in the shales over the top of the dome to admit oil into each sand lense, and at the same time to exclude water, as the lenticular sands seem to be free from water.

It is true that some shale oil is found in both of the fields in question. but the distance laterally to which oil follows the fissures in the shales is not great. Imperviousness of the shale body as a whole is a requisite for the retention of the oil, and it is probably true that the fissures are more open on

top of the dome than on the sides, and certainly the thickness of the shales here is less than that through which the Shannon oil is supposed to have moved. But notwithstanding this, the oil of the Wall Creek sands was not able to make its escape through the shales which cover the dome at their thinnest portion.

The argument that there is no known light oil pool in Wyoming where the Mowry shale is not present is not very strong proof that the Mowry was the source of the oil. The same argument might equally well be applied to any other formation which is present in all of the fields. I am not trying to minimize the importance of the Mowry shales as a source of light oil in Wyoming, but I think the dark shales of the rest of the Colorado group, and of the Montana as well, may have produced the oils of some fields, such as at Shannon and Big Muddy. The character of the Shannon oil is so different from the Salt Creek oils which come from the deeper horizons, that it does not seem likely it has filtered through the shale crevices to such a distance and finally accumulated in the form of a heavier product than the unfiltered portion which remained behind.

THE BEARING OF GEOLOGIC FEATURES IN SOUTH DAKOTA UPON OIL POSSIBILITIES[1]

ROY A. WILSON
University of Montana, Missoula, Mont.

INTRODUCTION

South Dakota has for some time received attention in the search for new areas of possible oil production, but only during the past two or three years have active plans been initiated for the prospecting of various parts of the state. Thus far, the efforts to test out different areas have been mainly directed toward the organization of local companies and the securing of leases, and few actual test holes have been drilled. Unfortunately, the majority of the development has not been backed by competent or reliable geologic advice and as a result the drilling projects, even if carried to the point of completing the holes, do not constitute fair tests of the state's oil possibilities.

The State Geological and Natural History Survey has been engaged during several field seasons in the study of the oil possibilities, the results being in part already published.[2] The following paper presents some of the geologic problems which have arisen during the course of these studies.

GENERAL GEOLOGIC FEATURES

Topography.—With the exception of the Black Hills uplift, the Big badlands of the White River region, and the Pine Ridge

[1] Published by permission of the State Geologist, State Geological and Natural History Survey, Vermilion, S.D.

[2] Freeman, Ward, "Oil in South Dakota," *Cir. 1*, Dec., 1917; "The Possibilities of Oil and Gas in Harding County," *Cir. 5*, Oct., 1918; "The Possibilities of Oil in Eastern Pennington County," *Cir. 8*, Oct., 1921.

Roy A. Wilson, "The Possibilities of Oil in South Dakota," *Bull. 10*, March, 1922. Freeman Ward and Roy A. Wilson, "The Possibilities of Oil in Western Dewey County," *Cir. 9*, Sept., 1922.

Roy A. Wilson, "The Possibilities of Oil in Northern Dewey County," *Cir. 10*, Dec., 1922.

district of the southwestern part of the state, the topography of South Dakota is characterized by rolling prairie. The land rises gradually from a general elevation of 1,200 feet in the extreme southeast to an average elevation of 3,000 feet in the west. The Black Hills rise to a maximum elevation of 7,242 feet. West of Missouri River the monotony of the rolling prairie is broken by scattered buttes and local badland areas. Several large areas of buttes occur in the northwest corner of the state.

In general the valleys of the important streams are well incised into the prairie surface and many of the streams are bordered by steep-cut banks. The smaller waterways occupy broad shallow valleys which may be locally much deepened. Most of the streams are depositing rather than cutting and hence meander over more or less well-developed flood plains.

Stratigraphy.—The distribution of the outcropping formations over the State is shown on Figure 1. Table I indicates the general character and thickness of the formations in various parts of the state.

Structure.—Aside from the Black Hills uplift and its northward and southward extensions the strata lie nearly horizontal. The slight folds which occur are in the form of gentle undulations, the regional dip rarely exceeding 1°. Detailed mapping of the structure in a restricted area has disclosed dips up to 5°, but these appear to be exceptional.

The broader structural features of South Dakota are shown on the geologic map by contours drawn on top of the Dakota sand and the top of the lower member of the Lance formation.[1] These contours are only approximate and it is quite probable that detailed studies of the structural features of the state will show wide variations in certain districts from this interpretation.[2]

OIL DEVELOPMENT

To the present no commercial oil deposits have been discovered in South Dakota. A number of the more pronounced folds in the

[1] N. H. Darton, "Geology and underground waters of South Dakota," *U. S. Geol. Survey*, Water Supply Paper, 227. See also *Bull. 627*, p. 37, and *691A*, p. 18.

[2] Note comment by W. T. Thom, Jr., Bull. Am. Assoc. Pet. Geol., vol. 6, p. 552, 1922.

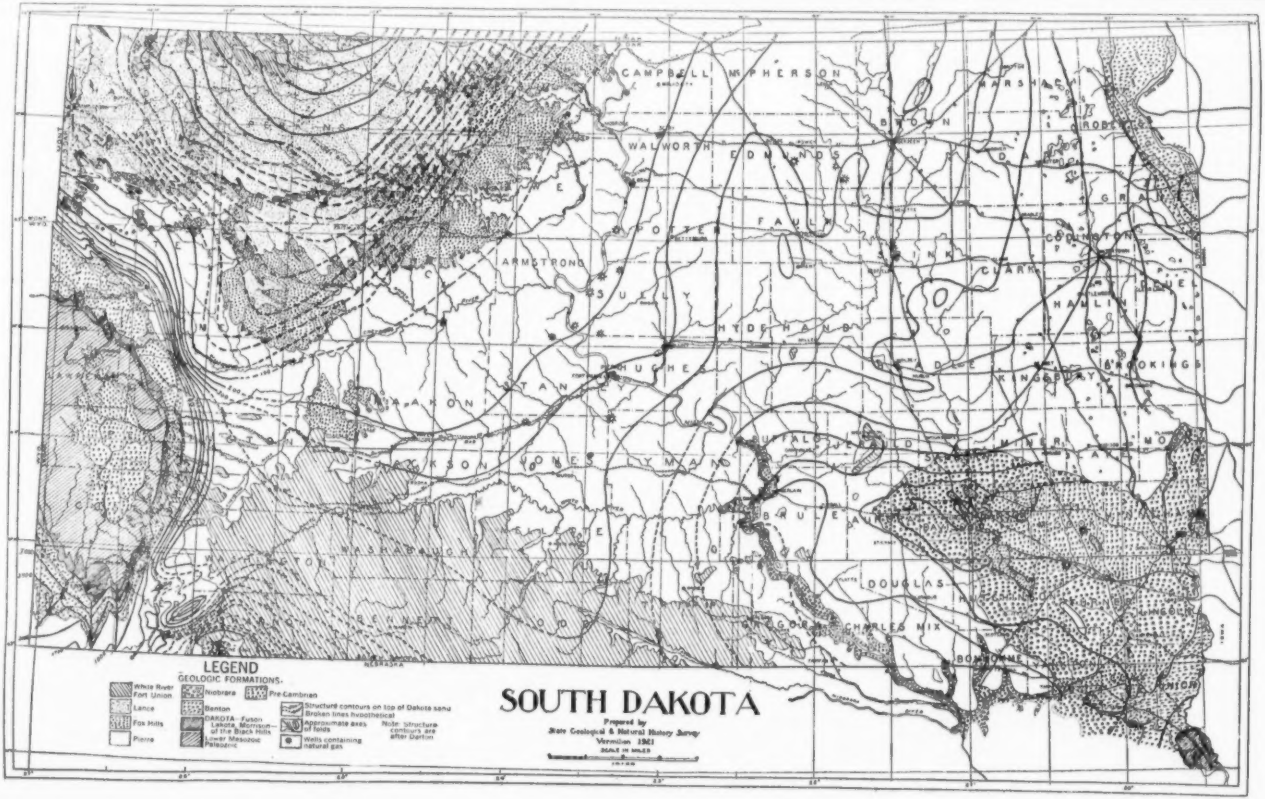
LEGEND
GEOLOGIC FORMATIONS
White River
Fort Union
Lance
Fox Hills
Pierre
Niobrara
Benton
DAKOTA - Fuson
Lakota, Morrison—
of the Black Hills
Lower Mesozoic
Paleozoic
Pre-Cambrian
Structure contours on top of Dakota sand
Broken lines hypothetical
Approximate axes of folds
Wells containing natural gas
Note: Structure contours are after Darton
SOUTH DAKOTA
Prepared by
State Geological & Natural History Survey
Vermillion 1921
SCALE IN MILES
CAMPBELL
MCPHERSON
MARSHALL
BROWN
ROBERTS
WALWORTH
EDMUNDS
FAULK
GRANT
CODINGTON
CLARK
HAMLIN
ARMSTRONG
SUTTON
HYDE
HAND
HUGHES
KINGSBURY
BROOKINGS
BUFFALO
JERAULD
MINER
MOODY
LAKE
DOUGLAS
CHARLES MIX
BON HOMME
UNION

TABLE I

Correlation Table of Formations in Eastern Wyoming and South Dakota

Era	Period, etc.		Eastern Wyoming	Black Hills	West and Northwest South Dakota	Eastern S. Dak.
CENOZOIC	Tertiary		White River	White River		
			Fort Union	Absent	Fort Union 425	Absent
	Tertiary or Cretaceous		Lance		Lance: Ludlow lignitic member 0–350; Cannonball marine member 0–225	
MESOZOIC	Cretaceous	Montana Group	Fox Hills sandstone; Parkman sand; Teapot sand		Somber beds 425; Fox Hills sandstone 25–400	
			Pierre shale; Shannon sand	1200–1400+	Pierre shale 1000+	
		Colorado Group / Benton	Niobrara	175–225	Niobrara chalk and shale 200+–	
			Carlile shale; Wall Creek sand	500–600	Carlile shale 200	
			Greenhorn limestone	65	Greenhorn limestone 25–50	
			Graneros shale (Mowry); Muddy sand	Mowry shale member 900–1150 Newcastle ss. member	Graneros shale 65–105	
		Dakota	Cloverly	Dakota ss 20–200; Fuson sh 30–150; Minnewaste ls 0–30; Lakota ss 100–300	Dakota (undifferentiated) 150–400	
		Comanchean				
	Cretaceous or Jurassic		Morrison	Morrison sh 0–150	Distribution and character of the formations under the Dakota are unknown	Pre-Cambrian granite and quartzite
	Jurassic		Sundance	Unkpapa ss 0–225; Sundance sh ss 100–300		
	Triassic		Chugwater, sh, ss.	Spearfish, sh ss 550–695		
PALEOZOIC	Carboniferous	Permian	Embar limestone	Minnekahta ls 30–50; Opeche sh 75–130		
		Pennsylvanian	Tensleep sandstone; Amsden formation	Minnelusa ss 400–500		
		Mississippian	Madison limestone	Pahasapa ls 300–600; Englewood ls 30–50		
	Ordovician		Bighorn limestone	Whitewood ls 0–80		
	Cambrian		Deadwood ls, sandstone	Deadwood ss		

region adjacent to the Black Hills uplift have been tested, and several of the wells have disclosed traces of oil. All of the sands down to and including the Deadwood formation (Cambrian) have been drilled into at one locality or another in the Black Hills region. The Chadron anticline in the southwestern part of the state, the most conspicuous fold outside of the Black Hills uplift, has been tested by several wells which have penetrated the formations at least down to the top of the Paleozoic. All of these tests have given negative results.

In the plains region no reliable tests for oil have as yet been made. A number of drill holes have been started in the western half of the state, but in no instance has the location of these wells been determined by competent geologic studies. As a result, these tests are of little value, aside from what sub-surface information they may secure.

Several thousand artesian wells have furnished fairly detailed knowledge of the sub-surface geology down to the Dakota-Lakota formations, especially in the eastern half of South Dakota where most of these wells are located. None of the artesian wells have shown positive indications of oil but not a few yield minor amounts of natural gas which comes to the surface occluded in the artesian water. The location of the wells yielding natural gas is shown on the geologic map.

Although prospecting for oil in South Dakota is still in its infancy, with positive tests restricted to the folded region of the Black Hills uplift, the present regional and sub-surface geologic evidence indicates that the possibilities for oil are not very promising.

POSSIBILITIES FOR OIL

Low dip structures.—Perhaps one of the outstanding reasons for the failure of geologists in the past to give serious consideration to the Great Plains region as an area of possible oil production has been the general absence of folds with the pronounced dips that characterize the productive structures in Wyoming and Montana. The recent discovery of oil in the Sweetgrass arch of northern Montana, which has a regional dip considerably under 5°, is the first striking exception to the general rule. Space does not permit

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	Cambrian		Deadwood sandstone	Deadwood ss 50–450		

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consideration of the various explanations offered for the general failure of low dip structures in the Rocky Mountain fields to produce oil, but low dips fold are not to be condemned entirely in the light of present geologic evidence.

Although the regional dip of the strata in the plains region of South Dakota is very slight, generally less than a degree and often not exceeding 10 feet to the mile, the writer believes that in so far as the structural factor is concerned any folds with a closure of 50 feet are worthy of testing. This figure is given as sufficiently large to allow for errors in mapping due to possible confusion of dips produced by local or superficial causes with those of a regional order. In a region of essentially horizontal strata it is often a difficult matter to differentiate between true regional dips and those of local origin, and this is especially true in South Dakota where false and superficial structures are common.

False and superficial structures.—The deciphering of geology in South Dakota from a study of the surface features is a difficult matter owing to the general absence of satisfactory outcrops and the widespread development of false or superficial structures. Practically all of the state east of Missouri River is covered with glacial drift and the determination of stratigraphy and structure must be based upon artesian well logs of which, fortunately, there are many hundreds. In the western half of the state, outside the region of the Black Hills uplift, outcrops of bedrock are not uncommon along the stream courses, in badland areas, and on the numerous buttes, but unfortunately, many of these outcrops have little value as indicators of the true regional structure.

As shown on the geologic map, the formations having an important areal distribution in the plains region west of Missouri River are the White River, Lance, Fox Hills, and Pierre. All of these formations are characterized by slumping, especially where they are exposed in the banks of streams. The soft shales of the Pierre exhibit slumping to the greatest degree, in fact so commonly that the writer places little reliance upon dips shown in this formation. Caution must be used in the recording of dip readings from the more consolidated beds of the Fox Hills sandstones and shales. False dips in this formation are produced by recent erosional

slumping; by the settling of slump blocks on the sides of channels cut into this formation by Lance Rivers;[1] and by the settling and tilting of outliers of the harder Fox Hills sand masses upon the soft underlying Pierre shales. The Lance and White River formations, owing to their generally unconsolidated character, are also readily susceptible to erosional slumping. The extreme lenticularity of the bedding, especially in the Lance, also makes structural mapping difficult, and this is further aggravated by the frequent presence of cross-bedding, often on a large scale.

Accordingly the writer believes emphatically that structure cannot be mapped satisfactorily in the plains region of South Dakota by the plotting of local dip readings alone. The plane-table method must be used and the greatest accuracy must be sought in recording elevation readings.

The only key beds satisfactory for mapping structure have been found in the Fox Hills formation. The coal beds in the basal part of the Lance formation are too localized and lenticular to give satisfactory results. Detailed plane-table mapping in the Fox Hills sandstone has shown that local dip readings in the various formations are of slight value as indicators of the true regional structure.

Sub-surface structures.—The present known facts concerning stratigraphy and structure in South Dakota suggest that a careful consideration of sub-surface structural features is essential in arriving at estimates as to the possibilities of oil production in the state.

While the relatively low dip of the surface formations over the plains region suggests that no pronounced deformation of these rocks will be disclosed beneath the surface, it is probable that the pre-Cretaceous strata which underlie a part of the state may, owing to intervening unconformities, contain folds not reflected at the surface.

Another factor involved in sub-surface structure is the part which the incompetent Cretaceous shales may have played in the vertical and horizontal transmission of stresses and the resulting effect upon surface folding. It is probable that the post-Paleozoic disturbances

[1] Freeman Ward, "The Lance Problem," December, 1922, meeting of the Geol. Soc. America.

have expressed themselves most strongly in the more competent of the Mesozoic formations, such as the Dakota-Lakota sandstones. The soft Cretaceous shales, on the other hand, have tended to absorb the stresses and thus have failed to transmit the folding to the surface to the degree in which it may be present in the underlying harder strata.

The possibility that a pre-Cambrian granite ridge extends between the Black Hills uplift and the Sioux quartzite region of eastern South Dakota is another factor meriting consideration in view of the effect of such a buried ridge upon the structure of the overlying formations.[1]

Possible reservoir rocks.—An unfavorable geologic factor bearing upon the possibility of oil in South Dakota is the probable absence or poor development of those sands which are productive in the Cretaceous of Wyoming and Montana. The logs of the hundreds of artesian wells which have been drilled into the Dakota-Lakota formations show that sand horizons are absent or poorly developed between the Fox Hills and the Dakota. This paucity of sands is explained by what is known of paleogeographic conditions during Cretaceous times. During the Colorado and Montana epochs, western and central South Dakota lay at considerable distances from the shore lines of the invading seas, and hence only the finest sediments were deposited in these areas. In the eastern and extreme western parts of the state sandstone layers are somewhat better developed in the Cretaceous, but no positive evidence of the presence of commercial oil deposits in these sands has been disclosed.

It is possible that, especially in western South Dakota, stray sands may be found in the Cretaceous shales, but such sands are likely to be thin and so greatly impregnated with silt and mud that they may have little value as reservoir rocks.

The Dakota-Lakota sandstones which underlie much of the state must be given serious consideration as possible reservoir rocks. These formations are oil-bearing in Wyoming and have shown traces of oil in the Black Hills region. The problem as to their possible productivity centers on two questions—Are structures

[1] W. T. Thom, Jr., "Oil Possibilities in South Dakota," *Bull. Am Assoc. Pet. Geol.*, Vol. VI (1922), p. 552.

satisfactory as traps for oil present in these sands? Has the active circulation of artesian water had a deleterious effect upon possible oil accumulation?

The first question has already been considered under the topic of buried structures where it was indicated that important structures in these formations may not be reflected at the surface owing to the incompetency of the thick section of soft overlying shales. The effect of artesian circulation upon possible oil accumulation involves a number of more or less indeterminate factors such as variation in porosity of the sands; the size and shape of folds and the resulting effect upon the movement of the water, oil, and gas; and the relation of saline waters found in certain wells to the general artesian circulation. Whatever future information may be disclosed upon these problems it is evident that the general artesian circulation is active as indicated by the hundreds of flowing wells in the eastern half of the state. Whether this circulation has kept the sands washed free of any oil which may have entered from the associated shales is a matter of conjecture, but the fact that none of the thousands of artesian wells have shown positive traces of oil has an interesting bearing upon this point. The reported presence of saline waters in some of the wells suggests the possibility of local areas of connate waters and hence inactivity of the artesian circulation. This possibility allows for the accumulation of oil and gas in such areas if the structural conditions are favorable. Over much of the west-central and all of the northwestern part of the state no wells have as yet penetrated to the Dakota sandstone, so that practically no information is at hand relative to the problems of the Dakota-Lakota sandstones in this general region. With folds of sufficient magnitude in these sands it is possible that their higher parts might be relatively free of the actively circulating waters and thus constitute favorable traps for oil and gas.

The possibility that favorable reservoir rocks may occur in the lower Mesozoic and Paleozoic where they underlie the plains region of South Dakota is a factor apparent to every geologist who has considered this region. With the exception of the wells drilled around the borders of the Black Hills and on the Chadron anticline,

the pre-Cretaceous strata have not been penetrated in the western half of the state and information is entirely lacking as to the character and development of the Paleozoic and lower Mesozoic rocks here. It is quite possible that important folds may be concealed in these formations by overlying unconformities.

Source rocks.—The thick series of Cretaceous marine shales is more or less petroliferous, as indicated by the general somber color, the local development of thin beds of oil shale, the presence of natural gas (dry) in a number of artesian wells, and traces of oil in interstratified sands on the eastern side of the Black Hills. In the region of the Black Hills uplift the Minnekahta limestone (Permian) is slightly bituminous. It is possible that other horizons of the Paleozoic and lower Mesozoic may contain favorable source rocks where they are developed under the plains region of the state.

Natural gas.—A considerable number of the artesian wells in central South Dakota contain small quantities of natural gas (Fig. 1). The writer believes that much of this gas is shale gas, given off from the shales into crevices and fissures from which it escapes to the surface through mixture with the artesian water under pressure when penetrated by wells. Such an origin is suggested by the low pressure and great variation in different wells; the small yield from individual wells (generally under 11 cubic feet per minute); the slight relation of distribution to structure or stratigraphy; the occurrence of the gas at different levels; and analysis of the gas which shows it is of the dry type and, as far as known, not associated with oil.

ON THE RELATIVE VALUE OF SPECIES OF SMALLER FORAMINIFERA FOR THE RECOGNITION OF STRATIGRAPHIC ZONES

THOMAS WAYLAND VAUGHAN[1]
U. S. Geological Survey, Washington, D.C.

INTRODUCTION

Because in some geological formations smaller Foraminifera are the most abundant fossils, and since, on account of their small size, the probability is greater that their remains will be better preserved than those of larger organisms, it is important to know the value they possess for the identification of stratigraphic zones. Such an evaluation is especially desired by petroleum geologists because of the efforts to identify horizons in well-bores and the attempts to decipher underground structure on the basis of the identification of particular beds by means of the species of these organisms. For these reasons, Mr. W. E. Wrather, President of the Association of Petroleum Geologists, and Mr. K. C. Heald, Chief of Section of the Geology of Oil and Gas Fields, of the U. S. Geological Survey, have requested me to prepare a statement on the subject.

The most satisfactory method of presenting the data would be to compile a table showing the stratigraphic range of each species at present known or reported from the American Tertiary formations, but this has not been practicable in the time at my disposal. In order to meet the needs of the interested geologists as well as I can, I have calculated the percentages of Recent species of smaller Foraminifera in each horizon of the Tertiary formations of the Coastal Plains of the United States, Panama, and the West Indies, for which data are available. Except those for the Choptank and Calvert formations of Virginia and Maryland, all of the identifications are by J. A. Cushman. The calculation of these percentages was relatively easy for me, because I had already

[1] Published by permission of the Director of the U. S. Geological Survey.

marked on most of the lists of fossil Foraminifera published by Cushman the names of the species which were also still living, in order that an idea might be formed of the geological duration of each species.

The percentage method here used is a very good one for purposes of stratigraphically evaluating the different groups of organisms discussed. The value of the method may be illustrated by reference to the percentage of Recent forms in the lower Oligocene Mint Spring calcareous marl. Of 81 identified species, of smaller Foraminifera only 38 can certainly be assumed as not also being Recent according to the list, or 53 per cent of the species would not permit distinction between Recent and lower Oligocene. These are, therefore, of no value for stratigraphic purposes. It seems that 22 species of the Mint Spring marl may be confined to it, but the Foraminiferal faunas are still only partially known, and when the percentages of Recent species in two lower Miocene formations, the Alum Bluff formation, between 77 and 88 per cent, and the Cercado formation, 93 per cent are considered, it appears very doubtful if there is a zonal distinction of such magnitude between the Foraminiferal faunas of the successive formations of the Vicksburg group. In any event, 25 per cent is about the maximum percentage of the smaller Foraminifera to which any stratigraphic significance may be attached, and it is more probable that the significant percentage is between 3 and 12. In order to use the species belonging to this percentage, between 3 and 12 per cent, of the entire fauna, these species must be singled out and clearly discriminated from the 88 to 97 per cent of the fauna which does not possess zonal value.

In the following discussion, especially in the table on page 526, the percentages of Recent species of smaller Foraminifera in different Tertiary formations are compared with the percentages of Recent mollusks supposed to characterize the Pliocene, Miocene, and Eocene according to Lyell, the Oligocene according to Beyrich, and the Paleocene according to Schimper.

These percentages are as follows: Pliocene, 30 to 50 per cent of the species of mollusks still living; Miocene, 17; Oligocene, 10 to 15; Eocene, 3.5; Paleocene, 0. As systematic work has

become more refined, the percentage of Recent mollusks recognized in the respective subdivisions of the Tertiary has greatly decreased, as shown by the table, on a subsequent page of this paper, giving a summary statement of the percentage relations. The Lyellian percentages of Recent mollusks, therefore, are too high. *The percentage of Recent mollusks in the lower Miocene ranges between* 3 *and* 7.5 *per cent; that of the smaller Foraminifera, between* 77 *and* 97 *per cent*!

The source of the data for calculating the percentages of Recent species of Foraminifera has been given above. The source of the data for the other groups of fossils is as follows: For the mollusks, Dr. Julia Gardner has given the percentages, based on her own work, for the Waccamaw marl, Duplin marl, and the Yorktown, and St. Marys formations; the estimates for the Caloosahatchee, Choctawhatchee, and Bowden marls, and the Choptank and Calvert formations are taken from Dall (1,2);[1] the estimate for the Gatun formation is based on the work of Brown and Pilsbry (1) and Cossmann (1); that for the Gurabo and Cercado formation is taken from Dr. C. J. Maury (1); and the estimates for the Byram and Mint Spring marls are from C. W. Cooke (1). The percentages for the corals are based on the writer's work (Vaughan) (1). It is interesting to note how nearly similar these percentages are to the percentages for mollusks for these formations in which there are rather large coral faunas. The percentages for the Bryozoa were calculated and furnished by Dr. R. S. Bassler.

It should be borne in mind that absolute correctness is not claimed for the percentages given in this paper, but it is believed that the relative orders of magnitude are correct. After the estimates were first made, they were checked and some figures were changed, but the changes did not affect the orders of magnitude. Difference in handling the data and subsequent information may change details, but it is believed that the general conclusion will not be altered.

It should be made clear that the discussion to follow applies to the smaller Foraminifera and not to the larger forms, which

[1] The numbers in heavy-faced type in parentheses after names of authors refer to papers the titles of which are given in the list of literature at the end of this paper.

include *Nummulites*, *Operculina*, *Heterostegina*, *Orthophragmina*, *Lepidocyclina* and allied genera, and *Dictyoconus*. The species of these genera appear to be of very restricted stratigraphic range and check admirably with the mollusks, corals, bryozoans, and echinoids. Some species of larger Foraminifera seem to range through two or three adjacent zones, but greater ranges have not been observed in the writer's own field studies or in the records of other stratigraphic geologists. These organisms, therefore, according to the available evidence, are dependable as zonal markers.

PLIOCENE

Waccamaw formation.—Cushman (1) records 23 species of Foraminifera from the Waccamaw formation, 19 of which are still living, 3 named species are known only as fossils, and 1 species is not named. On the supposition that the unnamed species is extinct, 83 per cent of the species are still living. Dr. Julia Gardner estimates that 35 per cent of the mollusks are also Recent. There are 24 species of bryozoa, of which 4 species, or 17 per cent, are Recent.

Caloosahatchee marl.—Thirty-three species and varieties of Foraminifera are reported by Cushman (1) from this formation. Of these, 27 are still living and of the 6 not reported as living one is not named. Eighty-two per cent of these forms are living. According to Dall (1) the percentage of living mollusks is 49. Eighteen species of corals are known from the Caloosahatchee, of which 8 species, or 44 per cent, are Recent. The bryozoan fauna comprises 19 species, of which 11 species, or 58 per cent, are still living.

MIOCENE

Choctawhatchee marl.—Thirty-six species of smaller Foraminifera are reported by Cushman (1), of which 25 species, or 69.4, per cent are Recent. Dall (1) records about 133 species of mollusks, of which 18 species, or 13.5 per cent, are Recent. There are 22 species of Bryozoa, of which 7 species, or 32 per cent, are still living. A single species of coral is known from the formation. It is extinct.

Duplin marl.—Twenty-four species of smaller Foraminifera are reported by Cushman (1). Of these, 18 species, or 75 per

cent, are still living. Miss Gardner finds that 27 per cent of the mollusks are Recent. The bryozoan fauna consists of 34 species, of which 13 species, or 38 per cent, are still living. Two species of corals, both of which are extinct, are known from the Duplin, but one species that is still living may occur in the formation.

Yorktown formation.—This formation, according to Cushman (1), has yielded 22 species of smaller Foraminifera, of which 17 species, or 77 per cent, are still living. Miss Gardner finds that 25 per cent of the molluscan species are Recent. The bryozoan fauna consists of 30 species, of which 7 species, or 23 per cent, are still living. Three species of corals, all extinct, are known from the Yorktown, but the formation may contain one species that is also Recent.

St. Marys formation.—Only 2 species of smaller Foraminifera, both still living, are reported from the St. Marys formation. According to Miss Gardner, 18 per cent of the molluscan species are Recent. Nineteen species of Bryozoa are reported, of which 5 species, or 26 per cent, are still living. The St. Marys has yielded 4 species of coral, all of which are extinct.

Choptank formation.—This formation has yielded 22 species of Foraminifera, of which, according to Cushman's (1) list, which is mostly based on identifications by Bagg, 20 species, or 91 per cent, are Recent. Dall (2) estimates that 11.4 per cent of the molluscan species are still living. The bryozoan fauna consists of 14 species, of which 2 species, or 14 per cent, are Recent.

Calvert formation.—Twenty-two species of smaller Foraminifera are recorded by Cushman (1) from this formation, but the identifications are mostly by Bagg. Of these species 21, or 95 per cent, are still living. According to Dall (2), the percentage of Recent species of mollusks is 9.3. The number of species of Bryozoa recorded is 12, one of which, or 8 per cent, is still living. The only species of coral known from the Calvert is extinct.

Alum Bluff formation.—This formation has yielded 18 species of smaller Foraminifera, according to Cushman (2). One of these is not determined and 3 species are supposed to be extinct. If the unidentified species is counted as an extinct species, 78 per cent of the species are still living; if the undetermined species is

dropped from the list, 82 per cent are still living. The molluscan fauna, according to Miss Gardner, contains only 3 per cent of Recent species. Five species of Bryozoa are known from the Chipola marl member of the Alum Bluff. Two of these species, or 40 per cent, are still living. The Alum Bluff coral fauna, including the Chipola, consists of 8 species, none of which are still living.

Gatun formation.—Forty-four species and varieties are recorded by Cushman (**3**), of which 37, or 84 per cent, are still living. Brown and Pilsbry (**1**) list 125 species of mollusks, and Cossmann (**1**) adds 4 species, a total of 129, of which 5 species, or 4 per cent, are supposed to be Recent. (See Vaughan, **2**.) Of the 3 species of Bryozoa known from the Gatun, 2 species, or 67 per cent, are Recent.

Bowden marl of Jamaica.—Cushman (**4**) lists 29 species and a variety of one species. Of these 30 forms, 1 species and 3 varieties are supposed to be extinct. If the varieties are assumed to be of specific value, 87 per cent of the forms are Recent. If the varieties are not considered, about 97 per cent of the species are Recent. Dall (**1**) estimated 12 per cent of Recent mollusks in the Bowden marl, but this figure is probably too high. Thirty-two species of Bryozoa are reported. Of these, 11 species, or 34 per cent, are Recent. Seventeen species of corals, of which 2 species, or about 12 per cent, are Recent.

Gurabo formation, Dominican Republic.—Only 2 species of Foraminifera, both still living, have been listed by Cushman (**5**) from this formation. There are about 70 species of corals in the formation, about 7 of which, or about 10 per cent, are Recent. Although the molluscan fauna has not been completely described, the percentage of Recent species is almost negligible. Dr. Carlotta Maury (1) finds about 7.5 per cent of Recent species in the combined mollusca she obtained from the Gurabo and Cercado formations. Only 6 species of Bryozoa are reported, of which 3 species, or 50 per cent, are Recent.

Cercado formation of the Dominican Republic.—Cushman (**5**) specifically identifies 30 species of Foraminifera from this formation, 28 of which, or 93 per cent, are Recent. There are 19 species of

corals known from the Cercado formation. Of these, 2 species, or about 10 per cent, are still living. The percentage of Recent mollusks is less than 7.5 per cent. Nineteen species of Bryozoa are reported, of which 4 species, or 21 per cent, are recent.

Yumurí marl of Cuba.—There are 28 names on Cushman's (4) list of species from this formation. Of these, 23 are positively identified, in two instances only the generic names are given, and in three instances the generic names are followed by "cf." One new variety and one new species are described. If it be assumed that there are 7 extinct species, the percentage of living species is 75. If the unidentified forms be rejected and the species to which the new variety belongs be counted as Recent, the percentage of Recent is 96. From other paleontological evidence, it is known that this formation is about the correlative of the Bowden marl, in which the percentage of still living mollusks is below 12 per cent. Four species of corals were obtained in the Yumurí marl. Of these, 1 species, or 25 per cent, is Recent.

OLIGOCENE

Emperador limestone of Panama.—Only 3 species of smaller Foraminifera, all Recent, are reported by Cushman (3). The coral fauna consists of 26 species, all of which are extinct. Two species of Bryozoa, one of them Recent, are reported.

Culebra formation of Panama.—Cushman (3) records from this formation 32 species of smaller Foraminifera, one of these is doubtfully identified, two are referred to as varieties of Recent species, 7 species are described as new, and 22 are identified with Recent species. If 7 species are accepted as extinct, 78 per cent of the species are Recent; if 10 species are accepted as extinct, 70 per cent of the species are Recent. None of the mollusks or corals are known in living faunas. The Culebra formation is considered by American workers to represent almost the top of the Oligocene; European invertebrate paleontologists would classify it as basal Miocene, that is Aquitanian. The data here given show that it would require close work to distinguish between a Recent and an upper Oligocene or basal Miocene fauna. According to the Lyellian

percentage, the smaller Foraminifera would indicate post-Pliocene as the age of the formation. One of the 7 new species also occurs in the Gatun formation. The recognition of the Culebra by means of smaller Foraminifera is, therefore, restricted to 6 species. As 82 per cent of the fauna are wide ranging, it does not appear safe to assume without corroborative evidence that 18 per cent of the fauna are stratigraphically restricted.

Byram Calcareous marl.—Cushman (**5**) records 66 species and varieties of smaller Foraminifera from the Byram calcareous marl, *Nummulites* sp. and *Lepidocyclina supera* (Conrad) not being counted as they are larger forms. Of these 66 the specimens of 7 species are said to be inadequate for specific description, and, therefore, these 7 species will be subtracted from 66, leaving 59. Of the 59 species and varieties, 25 are positively and 6 are doubtfully identified with forms still living, and 1 form is described as a variety of a Recent species. If 32 is assumed as the number of still living species, the percentage of Recent forms is 54. If 25 is assumed as the number of Recent species, the percentage of those still living is 42. None of the 5 species of corals are Recent. Cooke advises orally that of the 134 species of mollusks none are still living; and of the 45 species of Bryozoa recorded by Canu and Bassler, 4 species, or about 9 per cent, are also Recent.

Mint Spring calcareous marl.—Cushman (**7**) records the names of 84 species and varieties in his list of the Foraminiferal fauna of this member of the Marianna limestone. Three generic names are followed by "sp?" and these forms will be dropped from consideration, leaving 81 names. Of the 81 species and varieties 43 are also Recent; but the names of 5 species are followed by "var.," and one is marked "Cf." If 43 is taken as the number of Recent forms, the percentage of still living forms is 53; if 37 is taken as the number of Recent species the percentage is 46, or on the Lyellian percentage basis the deposit would be of Pliocene age. Cushman records 32 forms, one of them queried, as common to the Byram and Mint Spring marl. To these 32, the names of 27 forms, found in the Mint Spring marl and also Recent, should be added, for any Recent species that occurs in the Mint Spring marl may be expected

in the younger Byram marl. Subtracting 59 from 81, leaves a possible 22 species that may be peculiar to the Mint Spring. It should be stated that 4 of the species are represented in the Mint Spring by varieties.

None of the corals, Bryozoa, or mollusks of the Mint Spring marl are known to be still living. Cooke (1) says: "The list of species collected in the Mint Spring marl includes 160 mollusks and 3 corals. Of these, 81 occur also in the Byram marl, about 55 are found at Red Bluff or are represented there by varieties, and about 66 appear to be restricted to the Mint Spring marl." Ten species common to the Red Bluff and Byram have not been found in the Mint Spring. These 10 species should be added to the Mint Spring fauna and are taken into consideration in the following table:

PERCENTAGE RELATIONS OF CORALS AND MOLLUSKS IN THE RED BLUFF CLAY, MINT SPRING MARL, AND BYRAM MARL

(Based on figures of C. W. Cooke, 1)

	Red Bluff Clay	Mint Spring Marl	Byram Marl
	Per Cent	Per Cent	Per Cent
Peculiar	41	40	39
Also in Red Bluff clay	.....	38†	32
Also in Mint Spring marl	48*	.....	57
Also in Byram marl	37	50	.....

* Forty per cent known, 48 per cent expected.
† Thirty-four per cent known, 38 per cent expected.

PERCENTAGES OF RECENT FORAMINIFERA IN THE MINT SPRING AND BYRAM MARL

Mint Spring marl.....between 46 and 53 per cent
Byram marl .....between 42 and 54 per cent

The two foregoing tables show that there is the same order of difference between the species of fossil mollusks and corals of the successive formations of the Vicksburg group that there is between the smaller Foraminifera in the Byram and Mint Spring marls and the fauna of smaller Foraminifera living today.

TABLE SHOWING PERCENTAGES OF RECENT SPECIES OF MOLLUSKS, CORALS, BRYOZOA, AND SMALLER FORAMINIFERA IN AMERICAN TERTIARY FORMATIONS

Species and Formation Names	Lyellian: Percentage of Mollusks Still Living	Mollusks: Percentage Still Living According to Latest Available Estimates	Corals: Percentage Still Living	Bryozoa: Percentage Still Living	Smaller Foraminifera: Percentage Still Living	Ratio of Percentage of Recent Foraminifera to Recent Mollusks
Pliocene	30 to 50	.....	.....	.....	.....	.....
Waccamaw formation	.....	35	(1)	17	83	83/35
Caloosahatchee marl	.....	49	44	58	82	82/49
Miocene	17	.....	.....	.....	.....	.....
Choctawhatchee marl	.....	13.5	0[1]	32	69	69/13.5
Duplin marl	.....	27	0[1] to 33	38	75	75/27
Yorktown formation	.....	25	0[1] to 20	23	77	77/25
St. Marys formation	.....	18	0	26	100[6]	100/18
Choptank formation	.....	11.4	0	14	91[7]	91/11.4
Calvert formation	.....	9.3	0	8	95[7]	95/9.3
Alum Bluff formation	.....	3	0	40[2]	78 to 82	78 to 82/3
Gatun formation	.....	4	.....	67[3]	84	84/4
Bowden marl	.....	12	12	34	87 to 97	87 to 97/12
Gurabo formation	.....	7.5	10	50[4]	100[8]	100/7.5
Cercado formation	.....	7.5	10	21	93	93/7.5
Yumuri marl	.....	.....	25	.....	75 to 96	.....
Oligocene	10 to 15	.....	.....	.....	.....	.....
Emperador limestone	.....	.....	0	50[5]	100[9]	.....
Culebra	.....	.....	0	.....	70 to 78	.....
Byram marl	.....	0	0	9	42 to 54	42 to 54/0
Mint Spring marl	.....	0	0	0	46 to 53	46 to 56/0

[1] The coral faunas of the Waccamaw, Choctawhatchee, Duplin, and Yorktown formations are small. It is probable that one species found in them is still living and that the percentage of Recent species of corals is about the same as that of mollusks.

[2] Only 5 species of Bryozoa known from the Chipola marl member, 2 of these still living.

[3] Only 3 species of Bryozoa recorded, 2 of these Recent.

[4] Six species of Bryozoa reported, 3 of them Recent.

[5] Two species of Bryozoa reported, 1 of them Recent.

[6] Only 2 species of smaller Foraminifera, both Recent, reported.

[7] The identifications of species from the Choptank and Calvert formations are mostly based on the work of R. M. Bagg, Jr.

[8] Only 2 species of smaller Foraminifera, both Recent, reported.

[9] Only 3 species of smaller Foraminifera, all Recent, reported.

CONCLUSIONS

The value of organisms for stratigraphic zoning is inversely proportional to the stratigraphic range of the organisms. The data presented on foregoing pages show that the smaller Foraminifera possess the least value of any of the groups of organisms considered. There is a larger percentage of Recent species of small Foraminifera in the lower Oligocene Mint Spring marl than there

are of Recent species of mollusks in the Waccamaw Pliocene. About 50 per cent of the species of smaller Foraminifera in the lower Oligocene would not distinguish between lower Oligocene and Recent. The indications are that very nearly all the species are long ranging. From 77 to 93 per cent of the lower Miocene species are still living. It is obvious that probably 90 per cent of the species possess no zonal value. In order to use the small percentage of species that may possess zonal value those species must be distinguished from the larger number of species that possess no zonal significance. Faunas that possess from 75 to more than 90 per cent species in common may differ in age as much as Recent and lower Miocene; while faunas that possess 70 to 79 per cent species in common may differ in age as much as Recent and upper Oligocene. *The presence of a large percentage of identical species in cuttings from two different wells does not warrant the opinion on that evidence alone that the cuttings come from the same horizon.*

If the smaller Foraminifera are to be used for zonal purposes, a prime essential is to work out their stratigraphic distribution. In presenting data on stratigraphic distribution, a species must be shown as existing at all times between the time of the deposition of the oldest and that of the youngest formation in which it is known to occur. All the long-ranging species need to be recognized in order that they may be rejected. If the smaller Foraminifera are investigated in this way, after a time it may become possible to discriminate certain species that may have short stratigraphic ranges. But, it needs to be emphasized, this has not yet been done for any of the faunas of smaller Foraminifera in America. It is now only known that about 50 per cent of a lower Oligocene fauna will not distinguish it from a living fauna, according to data published by Cushman, the principal American student of these organisms.

With reference to zonal determinations by means of other organisms I will say that species that range through two formations are considered of only subordinate value. For example, mention may be made of a few corals that are not and a few that are of zonal value, according to present information. *Turbinolia pharetra* (Lea) occurs in the St. Maurice formation, the Gosport sand, and the

Jackson formation; *Platytrochus stokesi* (Lea) occurs in the St. Maurice and Gosport. These species are not of zonal value, because their stratigraphic range is too great. *Turbinolia claibornensis* Vaughan and *Sphenotrochus nanus* (Lea) are confined to the Gosport; and *Endopachys minutum* Vaughan and *Aldrichiella elegans* (Vaughan) are known only from the Jackson. These species are zonally significant. Other species of corals and species of mollusks, Bryozoa, and larger Foraminifera might be cited. But I cannot cite any species of smaller Foraminifera in which such confidence may be reposed; and in this connection it may be remarked that although I have often had considerable lists of species of smaller Foraminifera available for use, geological correlation has never been based on that group of organisms, as indicators of geological age.

Although species of smaller Foraminifera are of doubtful, and as yet undetermined value for zonal purposes, it seems probable that they may be used in distinguishing between major geological subdivisions, perhaps between Miocene, Oligocene, Eocene, and upper Cretaceous; but it appears that they cannot be expected to distinguish between lower Miocene and upper Oligocene and between lower Oligocene and upper Eocene. How reliable a discrimination may be made between lower Eocene and Upper Cretaceous, and between the different subdivisions of the Upper Cretaceous is still to be ascertained.

It may be possible to use the smaller Foraminifera in another way than as indicators of paleontologic zones of definite age—this is as constituents of sediments, particularly when the relations of the different beds composing the section and their relations one to another are known and are given proper consideration. It is well known that the recognition of such peculiarities of sediments as the presence of phosphatic granules, glauconite grains, and mica flakes, aid in the identification of beds penetrated by well bores. If a bed that occurs in certain ascertained relations to other beds is known to contain a certain kind of foraminiferal fauna, it is reasonable to expect that such a bed may be identified by means of its foraminiferal fauna. Studies of the local details of beds, including studies

of the foraminiferal contents of the sediments, may render important assistance in subsurface work, but faith should not be pinned to smaller Foraminifera alone. They should be considered as only one phenomenon among a group of associated phenomena.

There is danger in using Foraminifera in the manner just indicated, and I wish to make this danger clear. There may be in a section two or more beds that contain foraminiferal faunas of similar aspect and these beds may be confused; and there may be in adjacent or nearly adjacent areas beds of different ages but of similar facies. A good instance of two different geological formations of similar facies but of different age are the Vicksburgian limestones of Mississippi, Alabama, and western Florida, and the Ocala limestone of Florida and Georgia. Both of these limestones are characterized by an abundance of orbitoidal Foraminifera of superficially similar appearance and for years they were considered stratigraphic equivalents, but it is now known that the Ocala limestone is of Eocene age and, therefore, older than the Vicksburgian limestones. Two or more other instances of erroneous correlation of limestones of similar lithologic and faunal facies but of very different ages might be cited. In using Foraminifera as features of sediments in the identification of beds the same caution should be exercised that is taken in interpreting the significance of other constituents of the rocks. From available evidence similar faunas of small Foraminifera are indicative rather of similarity in ecologic conditions than of identity in age.

It is probable that the petroleum geologist may derive much assistance in the solution of his problems by the use of studies of the smaller Foraminifera, but he needs to bear in mind all of the uncertainties and dangers to which attention is here called. Intelligent application of the results of such studies requires a stratigraphic geologist of wide and varied experience.

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DISCUSSION

ESTHER E. RICHARDS: About three years ago, Mr. Dumble sent me to Florida to make collections of fossils from the type localities of the Upper Tertiary formations so that we might have them in our laboratory for comparative purposes in determining the various formations encountered in drilling

in the Gulf Coastal fields. This was done because no marine formations above the Jackson outcrop in Texas, but marine phases of the upper formations are present near the coast where they are buried under a series of overlaps.

We soon found that macroscopic fossils, were only very occasionally present in the well cores and cuttings examined and when present they consisted, generally, of broken, indeterminate fragments of some bivalve; of young and generally undescribed gastropods, or of long ranged forms which could not be used to place definitely or to separate the various horizons encountered. We then began to hunt for something on which we could rely as a definite means of formational determination and then discovered the possibilities of the foraminifera. Whereas in the case of the larger fossils only a few, rare, and indeterminate forms are generally found, even a small fragment of material in a fossiliferous zone carries a whole fauna of forams. Also, in a great many cases formations not generally otherwise fossiliferous do carry very splendid foraminiferal faunas. As Dr. Vaughan has stated the genera are long ranged, and there are many species present which closely resemble and occasionally are identical to present day forms, but an intensive study of several thousand samples of materials submitted from wells in Texas, Mexico, and Louisiana has proved to the satisfaction not only of our own company, but the Humble, the Texas, and other workers in this field that the major divisions of geological time—the Pliocene, Miocene, Oligocene, Jackson, Claiborne, Wilcox, Midway and various divisions of the upper and lower Cretaceous carry foraminiferal faunas which are sufficiently distinct and clearly defined to give us no difficulty in separating them easily and the still finer divisions of such formations as the Oligocene are now being worked on with every evidence of success in an attempt to draw definite lines of demarcation between the subdivisions of the major formations. The geographic provinces of the foraminifera are, faunally speaking, much narrower than those generally considered in the study of larger fossils and sections in various regions must be studied carefully for this reason, but there are many forms, consistently present in the same formation over wide geographical areas—as for example about 10 forms typical of the Taylor and its equivalents throughout Mexico, Texas, Louisiana, and Arkansas—forms which are always present and do not go above or below that formation.

THE RELATION OF THE REYNOSA ESCARPMENT TO THE OIL AND GAS FIELDS OF WEBB AND ZAPATA COUNTIES, TEXAS[1]

RICHARD A. JONES
Laredo, Texas

The oil and gas fields of Webb and Zapata counties, Texas, have reached a stage of development that has brought to them the full attention of the petroleum industry. The adjacent territory in Starr, Jim Hogg, Duval, McMullen, and Live Oak counties is also at present the object of much interest.

Webb, Zapata, and Starr counties border the Rio Grande, the Mexican state of Tamaulipas lying across the river. Jim Hogg, Duval, McMullen, and Live Oak counties are north and east of the three previously mentioned counties. The principal city of the section and the center of oil activity is Laredo, in Webb County on the Rio Grande, 150 miles south of San Antonio.

It is the purpose of this paper briefly to present the relation between the oil and gas fields and the Reynosa Escarpment, the most pronounced topographic feature of this part of southwestern Texas.

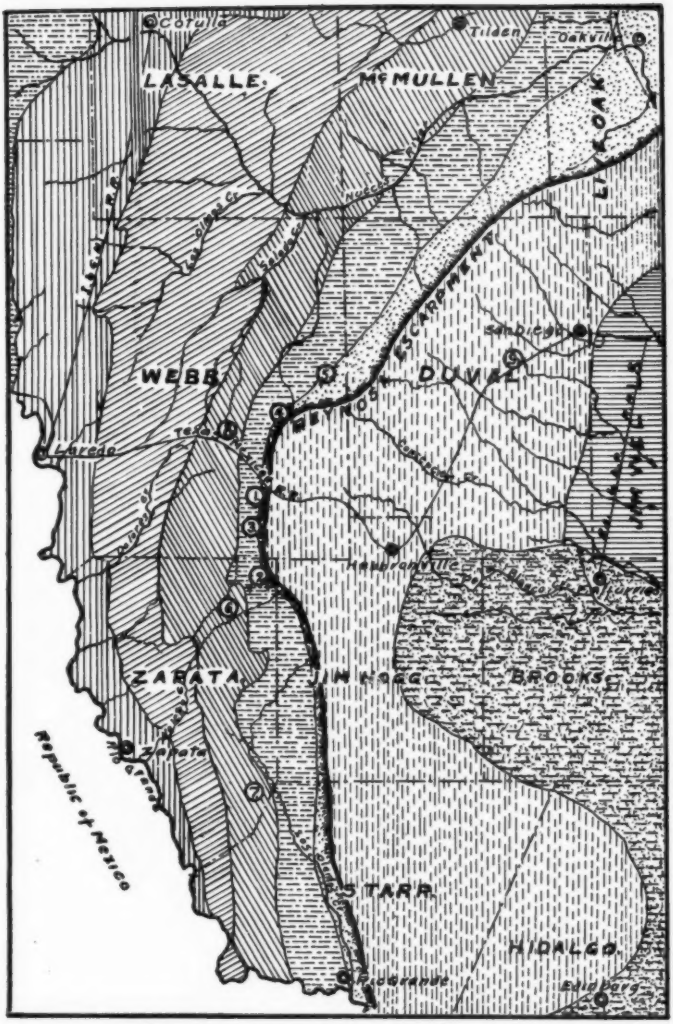
STRATIGRAPHY

In the Coastal Plain of southwestern Texas, rocks of Eocene, Miocene, Pliocene, Pleistocene, and Recent age outcrop. The area lies within the geologic province known as the Rio Grande Embayment. The areal distribution of the formations in Webb and Zapata and adjacent counties is shown on Figure 1.

Following is a generalized description[2] of the strata from Pliocene to Eocene inclusive:

[1] Published through the courtesy and with the permission of the Humble Oil and Refining Company, Houston, Texas. In the preparation of this paper the writer has benefited through the suggestions and criticisms of F. M. Getzendaner and Wallace E. Pratt.

[2] A full statement of the character of the beds may be found in various publications: "Review of the Geology of Texas," *Bull. 44, Univ. of Texas*, 1916; "The Geology of East Texas," by E. T. Dumble, *Bull. 1869, Univ. of Texas*, 1918; "Ground Water in Lasalle and McMullen Counties," by Alexander Deussen, *U. S. Geol. Survey*, Water Supply Paper 375, 1915; "The Geology of Southwest Texas," by E. T. Dumble, *Trans. A.I.M.E.*, Vol. XXXIII, 1902.



OIL & GAS FIELDS OF WEBB & ZAPATA CO'S

Recent, Sands, (Pleistocene & Windblown)

Pleistocene. Lissie

Pliocene. Reynosa

Miocene Pliocene. Oakville-Lapara

Eocene. Frio, Fayette, Yegua, Cook Mt, Mt Selman

① Shott-Mirando City Oil Field. ② Mirando Valley Oil Field. ③ Avalon Oil Field
④ Carolina-Texas Gas Field. ⑤ Leaseholders Oil Field. ⑥ Jennings Gas Field.
⑦ Charco Redondo Shallow Oil Field ⑧ Reiser Gas Field. ⑨ Piedras Pintas Shallow Oil Field.

PLIOCENE

Reynosa.—Caliche; gravel; sand; conglomerate; tuff; clay; calcareous, tuffaceous marl. Seldom has a thickness as great as 100 feet.

Lagarto.—Vari-colored, mottled clays and calcareous sands.

Lapara.—Interbedded sands and clays, often cross-bedded.

MIOCENE

Oakville.—Sands, grits, and conglomerates. The sands are coarse, often cross-bedded, and contain clay inclusions. Thickness 200–300 feet.

NOTE.—In many localities it is very difficult to make distinction between the Lagarto, Lapara, and Oakville. In the northern part of the region they can be differentiated, but in the central and southern portions the formations merge into one another so intimately that no accurate separation can be made.

EOCENE

Frio.—Pink and green clays with calcareous nodules; sandy clay; locally volcanic ash. Thickness 600–700 feet.

Fayette.—Brown and gray sandstones; lignitic clays; oyster beds; volcanic ash; silicified wood common. Thickness 400–600 feet.

NOTE.—In Lasalle and McMullen counties, the Frio and Fayette form zones of outcrop that are individual. In the region of the oil fields of Webb County this distinction has been lost. The two formations pass into one another so gradually that it is difficult to make a clean-cut, satisfactory distinction. The Fayette has here lost the pronounced sandstone facies, which forms conspicuous cuestas in McMullen County. Along the Rio Grande, the Fayette again takes on a more arenaceous character.

Vegua.—Principally gypsiferous, red, green, and purple clays; sandstone; oyster beds. Thickness about 600 feet.

Cook Mountain.—Glauconitic green sands; gypseous, sandy shale; iron ore and lignite; very fossilliferous.

Mount Selman.—Brown and bluish sands; iron ore; cannel coal. The Cook Mountain and Mount Selman are classified together as the Marine formation, the estimated thickness of which is 1,000 feet or more.

Carrizo.—Brown sandstone. Usually carries water. Thickness 150 feet.

Wilcox.—Yellow and blue shales with lignite; brown sands. Thickness 600–800 feet, much thinner on the Rio Grande.

Midway.—Basal, fossilliferous limestone, 12–15 feet thick; yellow and blue clays. Thickness 200 feet more or less.

OIL AND GAS

There are at present eight oil or gas fields in Webb and Zapata counties. These will be described briefly.

WEBB COUNTY

Schott–Mirando City oil field.—The Schott–Mirando City field is approximately 33 miles east of Laredo. The discovery well of the pool was Schott Oil Company No. 2 Garcia, which came in on December 10, 1921, as a gasser, later turning into an oil well. On March 16, 1922, Laredo Oil Company No. 2 was brought in, flowing at the rate of 1,500 barrels per day for five hours although salt water soon appeared and to date the well has not made a satisfactory producer. This well created widespread excitement as to the oil possibilities of Webb County.

On January 1, 1923, there were 51 producing oil wells and 7 gas wells in the Schott–Mirando City field. Fourteen holes have been dry or abandoned. Development is proceeding actively and the limits of the field are not yet known. The production of the field for November, 1922, was 105,301 barrels, a daily average of 3,510 barrels. This is the highest production yet recorded, the production for December, 1922, having dropped to 103,489 barrels, a daily average of 3,338 barrels. The pipeline runs for January, 1922, were only 422 barrels. The total yield for 1922 (exclusive of oil used for fuel) is 530,578 barrels of 21–22 gravity crude. The oil is transported by the Texpata Pipeline Company to loading racks on the Texas-Mexican Railroad at Mirando City, near the northern end of the field. The gas is used only for fuel in the field.

The average depth of the pay sand is 1,550 feet, the accumulation being dominated apparently by a fault of small throw with sharp folding on the east or upthrow side. The age of the producing horizon is probably upper Yegua or basal Fayette, although numerous well samples have been examined without yielding sufficient paleontological evidence to establish the age definitely.

Aviator's oil field.—The Aviator's pool, 4 miles south of the Schott–Mirando City field, was discovered on July 15, 1922, when the Aviator's Oil Company No. 1 Puig came in as an estimated 25-million gasser, spraying oil. On January 1, 1923, there were 6 producing oil wells and 1 gas well. Seven holes have been dry or abandoned. Drilling is active, although the production to date has been very small. The average depth of the sand is about 1,600 feet and the age of the petroliferous horizon is probably the same as in the Schott–Mirando City field. The gravity of the oil is the same. It is transported by the Texpata Pipeline Company. Recent developments between the Aviator's and the Schott–Mirando City fields lead to the belief that the two fields may possibly connect in the future.

Carolina-Texas gas field.—The Carolina-Texas gas wells are 9 miles northeast of the Schott–Mirando City pool. There are 4 gas wells in the field, the first of which was completed in November, 1921, and no oil has yet been found. One well produces from a sand at 1,300 feet; the other three wells produce from a lower sand at approximately 2,000 feet. The wells are of considerable volume, Carolina-Texas No. 4 Barnsley, the largest, being estimated at

40,000,000 cubic feet or more. There is considerable activity in this area, although up to the present no market for the gas has been provided.

Leaseholder's oil field.—The Leaseholder's Producing and Refining Company completed their No. 2 Gates Ranch, 25 miles northeast of the Schott–Mirando City field, early in November, 1922, with an initial production of 75 barrels daily. The gravity of the crude is 22 degrees B. The pay sand, which is probably Fayette, has a depth of 1,051 feet. Development in this area is now becoming active.

Reiser gas field.—The Reiser shallow gas field is 25 miles east of Laredo. It is the oldest field of the area, having been discovered in 1909. About 12 successful gas wells have been drilled, some of which are said to have made as high as 20,000,000 cubic feet daily. The city of Laredo was formerly supplied with gas from this field but the wells have declined, until now the gas is used only for fuel in the field. The pay horizon is at a depth of from 650 to 800 feet, the production probably coming from the Yegua. Some development is still in progress.

Zapata County

Mirando Valley oil field.—The Mirando Valley oil field is in the northeastern corner of Zapata County, near the common corner of Zapata, Webb, and Jim Hogg counties. It is about 3 miles from the Zapata-Webb county line, and about 2 miles from the Zapata–Jim Hogg county line.

The discovery well was Mirando Oil Company No. 3, which was brought in April 12, 1921. Previous to this, Mirando Oil Company Nos. 1 and 2 had been drilled unprofitably but were not bona fide dry holes, as both were junked and abandoned after a show of oil had been found. On January 1, 1923, there were 21 producing oil wells and 1 small gasser. About 30 holes have either been dry or have been abandoned for various reasons.

The total production of the pool for November, 1922, was 15,388 barrels, a daily average of 513 barrels; for December, 1922, the production was 11,064 barrels, a daily average of 358 barrels. The highest monthly production recorded for the field was for May, 1922, when 22,043 barrels were produced, a daily yield of 711 barrels. The production of the pool for the year 1922 (exclusive of oil used for fuel) was 193,784 barrels. The gravity of the crude is 21–22 degrees B. It is moved by the Texpata Pipeline Company.

The average depth of the wells is 1,450 feet. Production comes from a zone of sand and sandy shale of considerable thickness of probable Yegua (or younger) age. The sub-surface structure is that of a southeastward plunging anticlinal nose, the production being localized on a small terrace, as indicated by a widening of the contours. It is possible that the structure is closed on the west by a fault.

Jennings gas field.—The Jennings gas field, about 8 miles southwest of the Mirando Valley pool, was discovered in 1914. About 10 wells have been drilled into a gas sand which is found at depths of 1,200 to 1,300 feet. Wells

up to 10,000,000 cubic feet in size have been completed. The age of the producing horizon is probably Yegua. The city of Laredo is supplied with gas from the Jennings field.

Charco Redondo shallow oil field.—The Charco Redondo shallow field is in Zapata County about 25 miles south of the Mirando Valley field. About 21 wells have been drilled. The wells pump about 2 barrels daily for about a month; they then begin to fail, but, after a short rest, again produce normally. The gravity of the crude is 18–20 degrees B. There are no pipe line connections and the wells are shut down a large part of the time. The average depth of the wells is 150 feet, production being secured at depths of from 135 to 165 feet. On the western side of the field, the sand is found at 130 feet but is here unproductive; on the eastern side of the field, salt water is encountered at 175 feet The age of the producing horizon is Fayette.

THE REYNOSA ESCARPMENT

Topography.—The prevailing topography of the Gulf Coastal Plain of Texas, in which the oil fields of the Laredo district are located, includes uplands of low relief and broad river valleys. Toward the interior, the surface has sufficient elevation to escape the flat monotonous character of the plains immediately along the Gulf of Mexico, and is more or less broken. This latter topographic condition exists in Webb and Zapata and adjoining counties where cuestas with an abrupt descent on the west, but gentle slopes to the east or southeast, are formed by the outcrop of the more resistant beds.

Pre-eminent among the topographic features of the region is the Reynosa Escarpment[1]. The Bordas is a southwestward, westward, and northwestward facing escarpment, in places bold and rugged, presenting cliffs 25 to 100 feet high, and forming a landscape of striking and picturesque character, elsewhere subdued and indistinct. In spite of its variations, it can be traced through the entire area.

Starting near Nueces River (Fig. 1), the Reynosa Escarpment trends southwestward across Live Oak County, passing through the southeastern corner of McMullen County and the northwestern

[1] The name is derived from the Reynosa formation, which appears in the brow of the escarpment. It is believed that Dumble, in the course of his very valuable pioneer work in southwest Texas, was the first investigator to note and map this topographic phenomenon, which he called the "Bordas." E. T. Dumble, "Geology of Southwest Texas," *Trans. A.I.M.E.*, Vol. XXXIII (1902), pp. 5 f.

part of Duval County. Entering Webb County, it bends and crosses the Texas-Mexican Railroad just west of the station of Torrecillas in a direction almost north and south. Leaving Webb County, it again bends, and takes a southeastward course through the northeastern corner of Zapata County, thence trending east of south through Jim Hogg and Starr counties to the Rio Grande, a short distance southeast of Rio Grande City. Dumble[1] states that the adobe-capped ridges in the vicinity of Goliad and Beeville are a part of the escarpment.

The escarpment is capped by the gravel, sand, and caliche of the Reynosa formation and marks the contact of the Eocene and the Miocene-Pliocene beds. It is also a drainage divide west of which the streams flow south and west into the Rio Grande and north into Nueces River, while to the east the general flow is directly into the Gulf, though at the northern end some of the drainage enters the Nueces.

Structure.—The oil and gas fields of Webb and Zapata counties, to date, have been found immediately under the rim of the escarpment or but a few miles distant from it. The Reiser shallow gas field is about 8 miles west of the escarpment; the Jennings gas field is 8 miles southwest; the Charco Redondo shallow oil field is about 7 miles west; the Schott–Mirando City field, the Aviator's pool, the Carolina-Texas gas wells, and the Mirando Valley field are directly at the foot of the escarpment. The potential Leaseholder's field is about 5 miles from the nearest point on the scarp, but at the entrance of a large recess, so that in reality it is in close association with the escarpment. This relation of the fields and the Reynosa Escarpment may be only an interesting and remarkable coincidence. It is true that drilling has been far more intense in a general north and south line along the escarpment than either to the east or to the west of it. Nevertheless, the field evidence points to the fact that the close relation between the oil and gas fields and the escarpment is not merely a coincidence, but has structural significance

Along the entire front of the Reynosa Escarpment, the presence of silica in the form of chalcedony and opal is a noteworthy geologic

[1] *Loc. cit.*, p. 5.

occurrence. The rock occurs in three forms: (1) Plugs or knobs. Some of the plugs are of gray quartzite; others are of chalcedony and opaline silica. The chalcedony is in most cases gray-white, but often shows a variety of brilliant coloration and in a few instances a concentric, banded appearance. The surface weathering is often very rough. The knobs present the appearance of igneous plugs, which have been exposed by erosion. They form hills of such unusual character that they have everywhere been dignified by names. In southeastern McMullen County is a group of quartzite knobs, known as the "Painted Rocks" or the "Seven Sisters." In northern Duval County are "Los Picachos." In western Duval County is a group of four plugs, Cedro, Saladita, Sarnosa Grande, and Sarnosa Chica. It is thought that the chalcedony knobs of this area were first noticed and recorded by Dumble,[1] and by Hayes and Kennedy.[2] (2) As cementing material, binding together the sands and grits to form bedded quartzite. (3) As vein material, filling cracks. The vein chalcedony is in general gray-white in color, and often has a globular surface. In places also occur veins of silicified or cherty clay. These veins are found at many places along the escarpment from McMullen County to the Rio Grande.

The chemical composition of this silicic material may be seen from the following analyses[3] of samples from Los Picachos, Duval County.

ANALYSES OF ROCK FROM LOS PICACHOS, DUVAL COUNTY

	Per Cent	Per Cent
Silica	88.16	86.38
Ferric oxide	0.58	3.00
Alumina	1.23	2.91
Water	8.84	6.19
Lime	0.73	0.99
Magnesia	0.29	0.21
	99.83	99.68

[1] *Loc. cit.*, pp. 56, 57, 59.

[2] C. W. Hayes, and Kennedy, Wm., "Oil Fields of the Texas and Louisiana Coastal Plain," *Bull. 212, U. S. Geol. Survey*, 1903, p. 17.

[3] E. T. Dumble, *op. cit.*, p. 58.

The fields immediately adjacent to the escarpment have been found in recesses or re-entrant basins in the line of cliffs. A more precise and accurate statement is that the fields have been discovered near promontories or salients which extend westward from the main escarpment. In many instances the promontory is indistinct and broken, being represented by outliers only. Since the escarpment is retreating Gulfward under the attacks of erosion, salients are due to the presence in the line of retreat of hard rock, which resists degradation more effectively than the beds on either side. Associated with a number of the most prominent salients and obviously their cause for being is chalcedony or quartzite of the character described above.

Examples of the occurrence of silica in the vicinity of the oil and gas fields are as follows: (1) Schott–Mirando City field. Knobs of quartzite, associated with a finger of the scarp, between the northern and southern parts of the field. Blocks of the same material were formerly exposed in the streets of Mirando City but have recently been removed. Bedded quartzite and large boulders of the same material occurs a short distance west of Mirardo City. (2) Aviator's Field. A salient of the escarpment with Reynosa conglomerate, cemented with silica. (3) Carolina-Texas field. A sharp salient is present with bedded quartzite in the brow of the escarpment, $3\frac{1}{2}$ miles southwest of field. (4) The Leaseholder's field is at the entrance of a very wide and deep recess bounded on both sides by promontories. Five miles south of Leaseholder's No. 2 Gates Ranch outlying mesas show silicified clays. About 7 miles to the east in Duval County is a long salient marked by an abundance of silica-cemented material (Soledad Hills and Loma Atravasada). Just south of this promontory is a group of chalcedony plugs. (5) Mirando Valley field. A salient with outlying mesas. Chalcedony blocks 3 miles west of the field and bedded quartzite 3 miles southeast of the field. (6) Charco Redondo shallow field. Chalcedony vein material occurs on well dumps.

The presence of silica, causing induration of the beds at various points, and the consequent formation of the topographic features, of recesses and salients of the escarpment, with which the fields

are associated, appears to be a factor closely related to the occurrence of petroleum in this region. It is believed that the presence of silica is evidence of fissuring and faulting, probably accompanied by folding; that silica-charged waters have found passage through fault fissures and smaller cracks and have deposited silica in the various forms in which it is found wherever the proper conditions for precipitation existed; that the position of the Reynosa Escarpment tends to remain fixed by the resulting indurated rocks along the faults and fissures; and that the accumulation of petroleum in this area has been chiefly controlled by faulting (and attendant folding) which supplied channels for the circulation of petroleum as well as silica-charged waters.

The fields along the escarpment have a marked similarity and display similar peculiarities. The sub-surface maps do not show west dip, although there is an abundance of east dip. Production stops abruptly on the west. Gas is usually found on the western edge of the fields and oil to the east. Such conditions suggest that the same agencies, producing analogous structural conditions, have been at work in various localities, and that the structure thus produced is faulting with sufficient folding to form suitable reservoirs. In the Schott–Mirando City field, sub-surface evidence points to a small fault with sharp folding on the east or upthrow side as the cause of the oil accumulation. The manifestations of silica in the neighborhood of this pool are pronounced, and it appears very plausible to suppose that here the oil accumulation and the formation of the silica are both related to the faulting. In the Mirando Valley pool, while the evidence is more obscure, the same structural condition probably exists.

In northern Duval County, a short distance south of the McMullen county line and west of the escarpment is a small group of hills, Los Picachos, including two main hills and some smaller knobs. The hills are rugged, due to heavy beds of opaline silica, upended, so as to stand practically vertical. (This condition is interpreted as due to faulting of silica-replaced beds.) The strike of these tilted beds is N. 40 E. and can be traced from one hill to the other. A few yards from the vertical beds on the south side of one of the hills, are altered yellow-green clay shales, dipping 15

degrees, S. 50 E. and also striking N. 40 E. The silica is associated with aragonite and kaolin. In McMullen County, 2 or 3 miles from Los Picachos, and directly in line with the N. 40 E. trend of the vertical beds of opaline silica, is a group of quartzite plugs, the "Painted Rocks" or "Seven Sisters." These plugs are arranged in a N. 40 E. line.

There is in this area in Duval and McMullen counties, field evidence of a fault, the course of which is marked by silica knobs. It is logical to conclude that there is direct connection between the origin of the silica plugs and the fault, and that the silica was deposited by waters which circulated through fissures opened by the faulting. If the silica knobs are due to the combination of silica-charged waters and fissuring caused by faulting, it is a reasonable assumption that other marked occurrences of secondary silica in this region may be due to the same agencies. It is not necessary to postulate intrusive igneous rocks or magmatic waters as a concomitant of the chalcedony and quartzite knobs and other forms of silica, for cold meteoric waters are competent to transport silica in the form in which it appears in this area. Iddings[1] states that quartz from aqueous solutions, hot or cold, may be deposited in fissures or other cavities, or may be disseminated through a mineral mass as a more or less complete replacement of a former mineral.

All of the occurrences of quartzite or chalcedony knobs known to the writer are west of the Reynosa Escarpment, save at the shallow oil field of Noleda or Piedras Pintas, 3 miles northeast of Benavides, Duval County. In the old rock quarry at Piedras Pintas is a massive bed of gray quartzite dipping northward at an angle of about 10 degrees, and identical in appearance with that found at various points along the escarpment. The quartzite originally formed a hill, the rock of which was quarried and hauled away. Beneath the quartzite is kaolin. The mineral association is much the same as at Los Picachos.

The Piedras Pintas field is generally believed to be a salt dome. This does not mean that the quartzite and silica knobs other than that formerly at Piedras Pintas also overlie salt domes. In the fields of Webb and Zapata counties the drill has revealed no

[1] Joseph P. Iddings, *Rock Minerals*, 1911, 1, 539.

evidence of salt domes. The South Plains Oil and Gas Company No. 1 Coffield in the Schott–Mirando City pool was drilled to a depth of 3,009 feet with no sign of the presence of salt underlying the field. It is evident, however, that the former quartzite plug over the salt dome at Piedras Pintas and the various similar silica knobs along the escarpment are genetically related, and one factor common to all such occurrences appears to be faulting with consequent circulation of silica-bearing waters. The knobs and other widespread occurrences of silica along the Reynosa Escarpment have an important geologic significance.

The presence along the escarpment of silica, which has been interpreted as due to fissuring and faulting, as well as the character and the peculiar arrangements of the oil and gas fields, is evidence that the escarpment marks a line of structural weakness. The course of Nueces River strengthens this conclusion; its general course is south and east to the southern part of Lasalle County, where it turns abruptly at right angles to its former course and flows northeastward for approximately 50 miles to the vicinity of Oakville, Live Oak County, at which point it again suddenly turns at right angles, and flows southeastward into the Gulf at Corpus Christi. Nueces River is older than the beds forming the escarpment, and such a marked change in its course suggests that it may have been deflected by uplift.

The present position and appearance of the Reynosa Escarpment are determined by three factors: erosion, faulting, and the nature of the Miocene-Pliocene rocks. Erosion, degrading the Reynosa Plateau from the west, paused and became relatively fixed by the resistant silica rocks when the original erosion scarp reached the disturbed area along the fault zone. Probably, also, the escarpment owes its rugged aspect at places to fault scarps, which intensify the effect of erosion in producing cliffs and bluffs. The Oakville sands and the Reynosa gravel are likewise important in determining the topographic character of the escarpment.

The period of the initiation of movement along the Reynosa Escarpment cannot be stated with certainty, but the faulting and the infiltration of silica have continued until comparatively recently, into post-Oakville times and probably into the Reynosa, as the

chalcedony veins cut through all formations up to the surface deposits. The line of weakness marked by the Reynosa Escarpment may be an asymmetrical fold, with a long gentle east limb, and a very short steep west limb, fractured and faulted in places.

The writer presents the theory that the occurrence of oil and gas fields of this region in a general north and south line, for the most part immediately west of the escarpment, is due to the penetration by the drill of favorable, local structures, along a major line of weakness of which the Reynosa Escarpment is the generalized surface expression.

January 20, 1923

DISCUSSION

CHARLES H. ROW: In connection with the discussion as to the probable age of the fracturing in this area I wish to say that I have found quartz veins one-quarter of an inch in thickness and extending northeast and southwest, cutting through deposits of caliche, in the southwest part of Jim Hogg County, about three miles west of the Reynosa Escarpment. Several of these veins, running roughly parallel, were followed for perhaps one hundred feet where one or more of them disappeared, but in the same general direction were picked up again and traced in a more or less broken zone for a mile.

SIDNEY POWERS: The Reynosa formation, of which the Bordas escarpment is composed, is of erosional origin. The quartzite boulders in the vicinity of the escarpment may represent remnants of a stratigraphic horizon now eroded. The cementation of the quartzite could have been by fresh water.

DILWORTH HAGER discussed the origin of the silica and suggested that the oil accumulation was chiefly due to the local lenticularity of sands.

WILLIAM O. NELSON: In connection with Mr. Hager's statement that volcanic ash beds occur in the Reynosa Escarpment area, would say that if this volcanic ash is in the form of bentonite, the circulating waters would dissolve out the alumina in the bentonite, and would redeposit it as bauxite wherever these ascending waters would come in contact with surface waters containing organic acids, such as tannic acid.

R. A. JONES: I do not believe that the secondary silica could have been deposited with the characters which it shows in this region without channels through which the water circulated, i.e., fissures made by faulting. It is not likely that any other form of circulation would permit the formation of quartzite and chalcedony in definite trends, as N 40 E, for instance. The chalcedony and quartzite plugs along the fault in northern Duval and southeastern McMullen counties are definite proof that in one instance the deposition of silica has occurred along a fault. As stated in the paper, it is logical to conclude that other similar occurrences of silica may be due to the same cause.

I do not agree with Mr. Hager's statement that the character of the oil accumulation in the Schott–Mirando City field at Mirando City is chiefly due to lenticular sand conditions. There is subsurface evidence of a fault, with a downthrow on the west of at least 40 feet.

F. JULIUS FOHS asked concerning the possibility of deeper production in the area.

R. A. JONES: In answer to Mr. Fohs' question, there is a probability of deeper productive sands in the oil fields of Webb and Zapata counties. The South Plains Oil and Gas Company No. 1, Survey 460, Schott–Mirando City field, was drilled to 3,009 feet. A large thickness of sand, showing gas, was logged at approximately 2,850 feet. This is possibly in the Cook Mountain formation.

ALEX W. DEUSSEN: In answer to Mr. Hager's statement that the opal may be due to leaching of silica from the volcanic ash beds I wish to state that the volcanic ash beds continue clear across the state to Sabine River. No opal occurs east of Colorado River. It would seem that if volcanic ash were responsible for the opal such knobs would occur wherever the ash beds occur.

I would like to ask Mr. Jones what he considers to be the origin of the rhyolite boulders in the Oakville sandstones in Duval County, Texas.

R. A. JONES: Replying to Mr. Deussen, I think that the rhyolite boulders and the blocks of vesicular basalt in the vicinity of Government well, northwestern Duval County, may possibly have been transported from the west, for instance the area of igneous plugs in Uvalde County.

THE SPRING HILL–SAREPTA GAS FIELD, WEBSTER AND BOSSIER PARISHES, LOUISIANA

GERALD M. PONTON AND JOHN W. WHITEHURST
Shreveport, Louisiana

GEOLOGY

The area under discussion lies about fifty miles northeast of Shreveport and is reached from the towns of Spring Hill and Sarepta, on the Louisiana & Arkansas Railway. Two closely allied folds compose the field, that surrounding the Munn well on the east and that at the Lloyd Harris operation on the west. The western fold has been traced into Bossier Parish to the west, and it is not unreasonable to suppose that it may be extended into Arkansas to the north. The area covered may be defined as the greater portions of Townships 22 and 23 North, Ranges 9, 10, 11, and 12 West. The state of Arkansas bounds the area on the north. It will be noticed that the Haynesville field overlaps in Range 9 and the Plain Dealing area takes up a fair portion of Range 12.

The Cotton Valley gas field, lying to the south, is arbitrarily separated from the Spring Hill–Sarepta gas field by the south line of Township 22, but it is clearly marked off by a more or less well-defined fault. This fault has certain surface indications toward Homer, and, with the completion of the Fish Trap well in Sec. 7, T. 21 N., R. 9 W., and later with the completion by Dr. Webb of a 30,000,000-foot gas well in Sec. 13, T. 21 N., R. 10 W., in which the top of the Blossom sand was found 125 feet higher than in the Munn well, the existence of the fault has been generally conceded.

Without going into detail, it may be stated that, in the opinion of the writers, all gas and oil enrichment in this entire area is due to faulted conditions, but owing to the loose and soft nature of the formations and the variations in sand deposition, the enrichment has been erratic.

Thus far, about thirty-five wells have been drilled in the field, and six wells are drilling at present. Of the thirty-five wells, some

were junked, some were abandoned before reaching the producing sand, some were drilled through the sand without recognizing it, two blew in and were abandoned to prevent cratering, one cratered, and some, endeavoring to take too much sand, drilled into salt water. There are eleven wells completed which can be termed good commercial gas wells and two gas wells which can produce oil commercially, but at present with small production.

The name "Blossom" has been used to designate the producing sand. There is no definite evidence that it is the true Blossom, although we know it is the same sand as that developed in the Haynesville oil field. The Foraminifera in this "Blossom," while of the same species as those found in the formations above the Blossom, are larger, more symmetrical, and generally have straighter axes. This is apparent particularly in the form *Textularia*.

Figure 1 is a sketch map showing the manner in which the two folds may possibly be outlined. There is much information, which only wells can supply, still to be secured before the field can be outlined definitely. While it would appear that a closure exists east and south of both folds there is little or no information as to conditions north and west of them. The saddle shown between the two folds is assumed, as no wells have been drilled in this area. The Munn fold, it would appear, will eventually be worked out as a dome, but there is some doubt in the writers' minds with regard to closures on the western folds. The top of the producing sand is quite unreliable for plotting subsurface contours, as it has been proved in the three Lloyd Harris wells that the top of the sand shows as much as 18 feet vertical difference in 1,000 feet horizontally, though a hard rock parting. which in these three wells apparently separates the gas from the oil sand, is found at the same level. The sand deposition above this parting is also very erratic in nature in different parts of the field, changing from solid sand to streaks of sand and shale, and, in places, to pure shale. This erratic deposition has much influence, without doubt, in effecting the great difference in well pressures on the western fold. The writers prefer to ascribe this as cause for differences in pressure rather than to assume faulted conditions. Below the parting in the western fold, in every case where tests have been made and where cores have been taken,

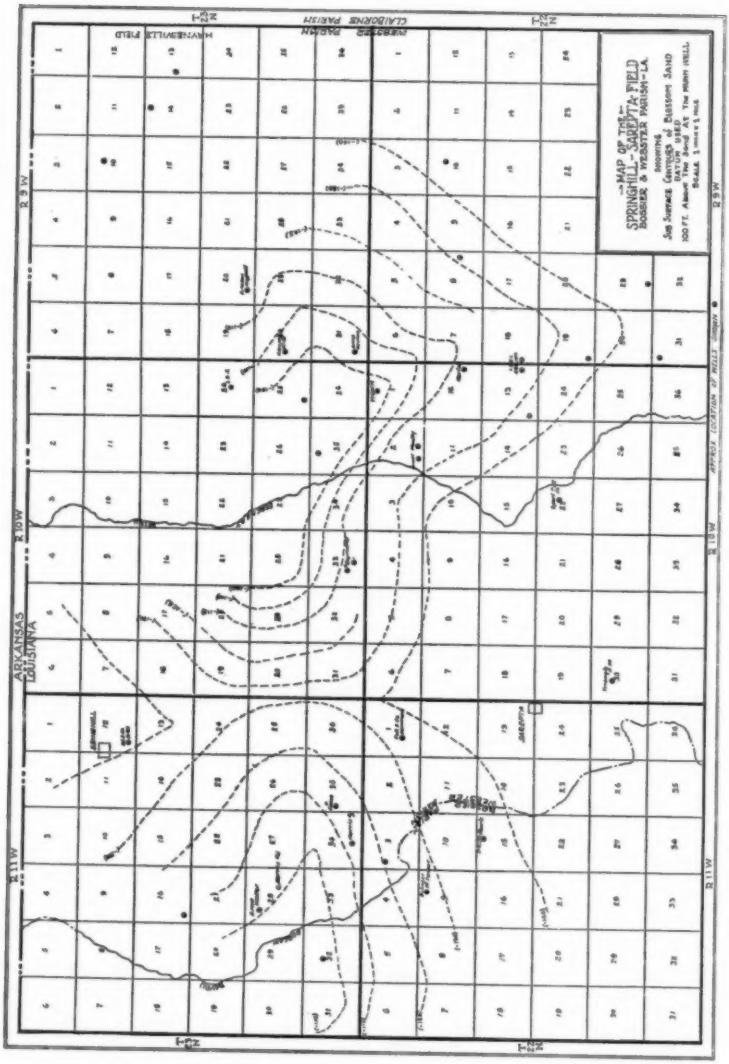

—MAP OF THE—
SPRINGHILL-SAREPTA FIELD
BOSSIER & WEBSTER PARISH-LA.
Sea Surface Contours on J. Blossom Sand
DATUM USED
100 FT. Above Sea Level At The Moon Hill
Scale 1 inch = 1 mile
CLAIBORNE PARISH
CRESCENT PARISH
HAYNESVILLE FIELD
ARKANSAS
LOUISIANA
T-22-N
T-21-N
R-11-W
R-10-W
R-9-W
R-8-W

FIG. 1

the sand appears solid and, except in case of wells off the structure, the cores have dripped oil.

Information as to thickness of the producing sand is very doubtful, as most of the wells blew in as soon as the sand was touched. However, 19 feet of sand was measured in one well on the western, and 18 feet in a well on the eastern fold. At the same time, wells which have been drilled off the structure and have made tests of the Woodbine sand, have recorded a small thickness of sand in the Blossom, and it is possible that on the structures, in places, this same condition will apply. In the Haynesville field, 17 to 35 feet of sand were taken and more or less erratic deposition existed.

Immediately above the producing sand, especially in the western fold, the formation varies considerably, running from hard, brittle shale to gummy shale and at times carries a streak of packed sand or sandy shale. In the Lloyd Harris No. 4, about six inches of solid rock salt was cored in sandy shale several feet above the top of the gas sand. Most of the wells completed have shown, to a greater or less extent, small amounts of salt water and it seems likely that this water comes in from the open hole. The writers would advise, therefore, that it is best to set 8-inch casing at about 2,600 feet and then set and cement 6-inch casing just above the gas sand: or, if testing for oil, the 6-inch should be set at the parting between the gas and the oil sands. If this latter procedure be followed, it will be necessary to core the sand thoroughly to determine this parting. Another suitable combination of casing would be $6\frac{5}{8}$-inch and $5\frac{3}{16}$-inch.

The log of Palmer–Pine Woods No. 1 is submitted as representative of the eastern fold and the Harris–Pine Woods No. 3 as typical of the western. This last log is a consolidated log of Harris No. 2 and No. 3 wells, and is the result of drill cuttings taken every ten feet in both wells and, in addition, of over 150 cores. The geological correlation is shown on the log of the Harris well below. It may be noted that the divisions indicated correspond closely to the correlation made by the U. S. Geological Survey for the Cooper-Henderson-Hammond No. 1 at El Dorado, Arkansas.

Many slides were made and all samples from Harris No. 2 and No. 3 wells were examined under the microscope. This work

was of considerable assistance in determining lithological characters, but it gave little aid in subdividing the formations on the basis of Foraminifera. However, the microscopic work is invaluable when used within the confines of a relatively small area, and should be used as much as possible in all wildcat operations, especially where more than one well is being drilled.

As an example, it was used to special advantage in studying the Arkadelphia clays. This formation is usually defined to include the beds lying between the Midway and Nacatoch. In the Spring Hill–Sarepta field these clays are devoid, so far as the writers can determine, of any well-defined Foraminifera from the top, at 1,090 feet, to 1,711 feet. At the latter depth a marly shale with streaks of chalk appears, which is almost entirely composed of Foraminifera, and this condition continues down to the Nacatoch at 1,850 feet. The writers, therefore, have separated this from the Arkadelphia clay and, by using it as a marker, have been most successful in estimating whether wells are running high or low.

GAS AND OIL

The eastern area, judged by present results, appears to be a bona fide gas field, although small showings of oil occurred in some of the wells. All wells on the western fold, which were finished in the upper part of the sand, are gas wells, but deeper tests carried through the parting have, in the Lloyd Harris Nos. 3 and 4 wells and the Morefield and Tanner well, demonstrated the possibility of the western area as an oil field.

The initial production of the gas wells runs from 10,000,000 to 50,000,000 cubic feet per day with a pressure from 1,000 to 1,200 pounds per square inch. No complete analysis of the gas has been made but tests for gasoline content have shown from 27 to 40 gallons of gasoline to the million cubic feet.

As to oil, the possible production of the Morefield and Tanner well is unknown as no liner was set and it is impossible to flow it safely. In September, 1922, the Lloyd Harris No. 3 was completed, flowing at the rate of several thousand barrels of oil with 20,000,000 feet gas daily, but owing to high pressure and loose sand, it could not be commercially produced. This well has since been re-worked

and it appears at present that it will be good for about 250 barrels per day, flowing through a $\frac{7}{8}$-inch choke. Harris No. 4 well, which was completed just in the parting between the gas and oil sands, when allowed to flow wide open, sprays about 50 barrels of oil with 20,000,000 feet gas.

The following is an analysis of the oil from the Harris No. 3 well: Baumé gravity, 26–28; benzine 33.3 per cent, 34.9 Baumé; fuel oil 60 per cent, 23.6 Baumé; water 5 per cent; loss 1.7 per cent. Benzine analysis: Kerosene 6.7 per cent; gas oil 92.8 per cent; loss .5 per cent. Separate analysis for gasoline content showed 1.5 per cent.

OTHER POSSIBLE OIL AND GAS STRATA

On the folds, the bottom of the Midway usually shows a little gas with dead oil and brackish water.

The middle of the Nacatoch shows some gas, and in the Harris No. 4, where tested—but with 8-inch casing set too high—it showed possibility of being a small producer of oil. The writers advise that, in all wells drilling in new parts of the field, this sand should be watched very carefully.

The Marlbrook marl, at 2,178 feet in Harris No. 2, was tested and developed gas with a flow of over half a million feet a day. It is possible that this is the same member which is producing in Sec. 5, T. 16 S., R. 15 W., of the West Smackover field, Union County, Arkansas.

Two wells on the structures have been drilled to a sand in the neighborhood of 3,100 feet, generally thought to be the Woodbine, but both tests were unsatisfactory. One of the tests, however, resulted in a showing of gas and oil.

Record of the Palmer et al.–Pine Woods No. 1 well, Sec. 35, T. 23 N., R. 10 W., Webster Parish, Louisiana.

Loc. 200 feet N. 242 feet E. SW. Cor. NW¼ NE¼.	From	To	
	0	60	Surface sand
Elev. 223 feet.	60	62	Rock
Total Depth 2,662 feet.	62	70	Sand
Casing Record, 10-inch at 227, 8-inch at 1,031, 6-inch at 2,562.	70	72	Rock
	72	90	Sand and boulders
Commenced 9–9–22.	90	146	Rock
Completed 10–16–22.	146	160	Shale
I. P. 25,000,000.	160	200	Shale and sand

From	To		From	To	
200	201	Rock	1,210	1,276	Shale and boulders
201	227	Shale	1,276	1,430	Shale and gumbo
227	300	Sand	1,430	1,490	Gumbo
300	302	Rock	1,490	1,650	Shale and boulders
302	390	Sand	1,650	1,697	Gumbo
390	400	Gumbo	1,697	1,713	Chalk rock
400	440	Shale	1,713	1,790	Shale
440	500	Sand and shale	1,790	1,800	Gumbo
500	502	Rock	1,800	1,850	Lime and shale
502	670	Shale and sand	1,850	1,904	Hard lime and shale
670	680	Gumbo	1,904	1,933	Lime
680	720	Shale	1,933	2,050	Gumbo and lime
720	800	Shale and boulders	2,050	2,100	Tough gumbo
800	801	Rock	2,100	2,145	Tough gumbo and lime
801	866	Shale and boulders	2,145	2,150	Gumbo
866	867	Rock	2,150	2,170	Lime rock
867	882	Gumbo	2,170	2,240	Shale and gumbo
882	884	Rock	2,240	2,265	Shale and boulders
884	985	Shale and gumbo	2,265	2,480	Lime rock
985	986	Rock	2,480	2,552	Shale and gumbo
986	1,031	Shale and gumbo	2,552	2,562	Gumbo
1,031	1,049	Gumbo	2,562	2,572	Tough gumbo
1,049	1,050	Rock	2,572	2,585	Gummy shale
1,050	1,125	Sandy shale	2,585	2,639	Sandy shale
1,125	1,154	Gumbo	2,639	2,650	Shale
1,154	1,190	Shale and boulders	2,650	2,651	Cap rock
1,190	1,191	Rock	2,651	2,662	Gas sand
1,191	1,210	Gumbo			

Record of the Lloyd Harris–Pine Woods No. 3 combined with No. 2, Sec. 34 T. 23 N., R. 11 W., Webster Parish, Louisiana.

Loc. 150 feet S., 300 feet W., NE. Cor., SW¼, SE¼.
Elevation 232 feet.
Total Depth: 2,698 feet.
Casing Record: 12-inch at 213, 8¼-inch at 1,360, 6¼-inch at 2,645.
Commenced 5–25–22.
Completed 8–29–22.
I. P. 8,000? Oil 10,000,000 Gas.

From	To	
		St. Maurice (?)
0	6	Surface
6	25	Red clay
25	60	Sand, mostly dry
60	65	Clay
65	149	Water sand
149	150	Lignite
150	155	Clay and boulders
		Wilcox sand
155	170	Fine gray clay
170	198	Water sand, lignite and gravel
198	207	Hard sand and rock
207	238	Gumbo
238	253	Sand, boulders and lignite
253	273	Gumbo
273	313	Sand and boulders
313	328	Sand and lignite (artesian water)
328	335	Gumbo

From	To	
335	350	Sandy gumbo
350	396	Sand and few boulders
396	406	Gumbo and boulders
406	461	Sand, boulders and streaks of green fossiliferous shale
461	473	Gumbo and boulders
473	480	Sand and boulders
480	492	Green sandy gumbo
492	528	Hard gummy shale with fossils and little sand
528	548	Gumbo
548	563	Hard gummy shale
563	609	Gumbo with few small streaks black sand
609	619	Sandy shale
619	634	Brown gummy shale
634	639	Hard green sand and fossils
639	644	Brown gummy shale
644	658	Gumbo
658	673	Shale and gumbo
673	680	Sand rock
680	715	Gummy shale
		Midway
715	730	Shale and small flint boulders
730	738	Gumbo and little lignite
738	773	Light gummy shale
773	795	Sandy shale
795	875	Brown shale with little lignite and marl
875	878	Flint boulders
878	880	Fine gray sand
880	883	Lignite
883	910	Gummy shale and little lignite
910	912	Flint boulders
912	918	Gumbo
918	922	Lignite
922	934	Gummy shale, some lignite and sand (brackish water)
934	940	Fine gray sand
940	952	Sandy shale
952	961	Gumbo and small flint boulders
961	969	Fine gray sand and lignite
969	974	Gumbo
974	979	Lignite
979	998	Sandy gumbo (brackish water)
998	1,005	Lignite
1,005	1,012	Gumbo
1,012	1,023	Flint boulders
1,023	1,038	Gray sand and streaks of lignite and brown shale, oil show, very heavy oil with water
1,038	1,048	Brown shale, little lignite and sand
1,048	1,054	Flint boulders
1,054	1,076	Sandy shale, little lignite and few small boulders
1,076	1,078	Gypsum
		Arkadelphia clay
1,078	1,090	Sandy shale, gypsum
1,090	1,096	Gumbo
1,096	1,097	Flint boulders
1,097	1,126	Gumbo and gypsum
1,126	1,127	Flint boulders
1,127	1,130	Gumbo and gypsum
1,130	1,132	Flint boulders
1,132	1,165	Gumbo and little gypsum (possible top of Arkadelphia clays)
1,165	1,169	Flint boulders
1,169	1,231	Gummy shale
1,231	1,232	Flint boulders
1,232	1,245	Gumbo and small boulders
1,245	1,300	Gummy shale, small streaks sand, little lignite and few boulders
1,300	1,350	Gummy shale, small streaks sand and few boulders
1,350	1,379	Gumbo
1,379	1,404	Soft dark shale
1,404	1,440	Gumbo and few soft boulders
1,440	1,480	Soft dark shale
1,480	1,486	Gumbo
1,486	1,494	Soft dark shale
1,494	1,500	Gumbo and some lignite
1,500	1,522	Soft dark shale
1,522	1,535	Gumbo
1,535	1,591	Soft dark shale with hard sand streaks toward bottom

From	To	
1,591	1,639	Hard gummy shale
1,639	1,668	Gumbo
1,668	1,683	Shale
		(?) formation
1,683	1,711	Hard gummy shale
1,711	1,747	Chalk
1,747	1,764	Hard shale with little lime rock
1,764	1,814	Hard shale
1,814	1,830	Hard shale, some chalk and coral
1,830	1,831	Hard lime
		Nacatoch sand
1,831	1,851	Hard shale, some chalk and streaks of very hard lime
1,851	1,871	Hard brittle shale, small streaks sand and very hard lime, slightly salt water
1,871	1,893	Lime rock with streaks hard sand and dark soft shale
1,893	1,908	Hard shale, sand and chalk
1,908	1,916	Fine grained sharp sand, dry
1,916	1,922	Gummy shale and sand
1,922	1,952	Hard shale
1,952	1,962	Hard shale, sand and chalk
1,962	1,975	Hard lime, streaks, sand and chalk
1,975	1,987	Hard shale and chalk with streaks fine sharp sand
1,987	1,996	Sandy lime, chalk and shale
1,996	2,010	Very fine sharp sand, oil show possibly some gas
2,010	2,016	Limy shale and blue chalk
		Marlbrook marl
2,016	2,046	Hard shale, blue chalk and streaks hard sandy shale (salt water)
2,046	2,087	Blue chalk and small streaks limy shale
2,087	2,094	Tough gumbo
2,094	2,149	Hard shale, gumbo and very little chalk
2,149	2,178	Limy shale with little sand (gas)
2,178	2,194	Gumbo and little shale
2,194	2,204	Hard brittle shale
2,204	2,218	Hard brittle shale and white chalk
2,218	2,254	Soft shale, chalk and very little sand (salt water)
2,254	2,276	Soft gummy shale and little chalk
2,276	2,288	Shale with large shells
2,288	2,313	Shale, gumbo and chalk
2,313	2,321	Limy shale
2,321	2,328	Gumbo
2,328	2,359	Soft limy chalk
		Annona chalk
2,359	2,376	Hard gummy shale
2,376	2,396	Hard limy shale
2,396	2,409	White chalk with streaks hard limy shale (salt water)
2,409	2,420	Hard limy shale and little chalk
2,420	2,426	Chalk with small streaks limy shale
2,426	2,445	Brittle shale and chalk
2,445	2,478	Chalk rock
2,478	2,496	Chalk rock with streaks hard limy shale
		Brownstown marl
2,496	2,536	Chalk rock and hard limy shale
2,536	2,545	Gumbo
2,545	2,554	Brittle shale
2,554	2,559	Gumbo and hard shale
2,559	2,564	Gumbo
2,564	2,598	Gumbo and hard shale
2,598	2,621	Gumbo and little shale
2,621	2,641	Hard shale
2,641	2,645	Gumbo
2,645	2,656	Hard gummy shale
		Blossom sand
2,656	2,681	Hard shale, slightly limy and sandy in spots
2,681	2,690	Very hard limy shale with streaks of sandy shale (gas and some oil)
2,690	2,696	Very hard limy shale and streaks of sand
2,696	2,698	Sand (oil)

GAS PRODUCTION FROM THE SPRING HILL–SAREPTA GAS FIELD, WEBSTER AND BOSSIER PARISHES, LOUISIANA

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PROBABLE LIFE OF THE FIELD

The present defined area of the Spring Hill–Sarepta gas field, in Webster and Bossier parishes, Louisiana, is approximately 50 square miles and the thickness of the producing gas sand averages about 15 feet. Assuming the porosity as .20, which is lower than that used for calculations in the Monroe gas field, and an average initial rock pressure of 1,200 pounds, calculation of the gas content for this area may be made as follows:

$50\times5{,}280\times5{,}280\times15\times.2=4{,}181{,}760{,}000$ cubic feet of gas in reservoir at rock pressure of 1,200 pounds.

$$\frac{4{,}181{,}760{,}000\times(1{,}200+14.7)}{(.5+14.7)}=334{,}540{,}800{,}000$$ cubic feet of gas in the reservoir at a pressure of 8 ounces above atmosphere. If 80 per cent of this gas is considered recoverable, this field will yield 267,600,000,000 cubic feet at 8 ounce pressure.

Of the eleven gas wells successfully completed in the field, only five wells were drawn on for consumption in 1922. These five wells are as follows: (1) Munn No. 1, initial rock pressure 1,215 pounds and initial open-flow capacity of approximately 60,000,000 cubic feet; (2) Wise No. 1, initial rock pressure 1,150 pounds and initial open-flow capacity of approximately 35,000,000 cubic feet; (3) Jordan & Young No. 1, initial rock pressure of 1,205 pounds and initial open-flow capacity of approximately 42,000,000 cubic feet; (4) Pine Woods No. 1, initial rock pressure of 1,200 pounds and initial open-flow capacity of approximately 35,000,000 cubic feet; (5) Martin No. 1, initial rock pressure 1,040 pounds and initial open-

flow capacity of approximately 40,000,000 cubic feet. These wells show a combined initial open-flow capacity of 212,000,000 cubic feet and a rock pressure varying from 1,040 to 1,215 pounds.

The total send-outs of the wells named up to December 31, 1922, are as follows:[1] (1) Munn No. 1, 12 months, 1922, 3,350,000,000 cubic feet; (2) Wise No. 1, 4½ months, 1922, 800,000,000 cubic feet; (3) Jordan & Young No. 1, 8 months, 1922, 880,000,000 cubic feet; (4) Pine Woods No. 1, 2 months, 1922, 250,000,000 cubic feet; (5) Martin No. 1, 6 months, 1922, 777,000,000 cubic feet. The total send-outs for gas consumption from the five wells amounted to 6,057,000,000 cubic feet as of December 31, 1922, which represents an average withdrawal of 17,000,000 cubic feet per day. The first year withdrawals therefore represent less than 2½ per cent of the total available gas yield. The total send-out of gas at present from these same five wells averages around 20,000,000 cubic feet daily.

Figuring the available supply of gas in the Spring Hill–Sarepta field at 267,600,000,000 cubic feet, and with a daily consumption of 20,000,000 cubic feet for the entire field, the life of the field will be approximately 37 years. If it is assumed that the maximum withdrawal from the field will reach within three years 60,000,000 cubic feet per day, and remain constant at this figure, the life of the field will be approximately 15 years.

ANALYSIS OF GAS

No chemical analysis of the gas in this field is available. Specific gravity tests made on two of the wells show .53 in both instances, which is lower than the specific gravity of the gases in the Monroe field. These same samples showed a gasoline content of 45 to 47 gallons to the million cubic feet.

DISTRIBUTION OF GAS

The gas is distributed to the Haynesville oil field, the town of Haynesville, the Homer oil field, and the town of Homer. No attempt has been made to use the gas for the manufacture of carbon black.

[1] Figured at 8 ounce pressure.

The appended table shows the location and depth of the five wells:

Name of Well	Location	Elevation	Top of Sand	Total Depth
Munn No. 1	1–22–10	236	2,658	2,662
Wise No. 1	30–23–9	297	2,717	2,722
Jordan and Young No. 1	33–23–10	203	2,641	2,658
Pine Woods No. 1	35–23–10	219	2,650	2,662
Martin No. 1	12–22–10	219	2,656	2,673

NOTES ON THE SIMPSON FORMATION, OKLAHOMA

FANNY CARTER EDSON
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INTRODUCTION

The Simpson is an Ordovician formation consisting of limestone, shale, and sandstone which outcrops in and around the Arbuckle Mountains in south central Oklahoma. It was recognized first and described by Taff.[1] It is one of the oldest oil-producing horizons in the Paleozoic section, and therefore interests petroleum geologists.

This paper presents a brief summary of available information on the Simpson and its equivalents and a petrographic study of samples collected in the Tahlequah area.

The outcrops of the Simpson formation are shown in Figure 1. In the Arbuckle Mountains the formation is, on the average, about 1,740 feet thick. It apparently lies unconformably on the Arbuckle limestone, as is shown by the fact that the basal member, a massive sandstone, varies in thickness from place to place, or is absent locally. Above the lower Simpson sandstones, the middle Simpson consists of about 1,282 feet of shales and limestones mainly. The upper Simpson is, like the lower, a sandstone averaging about 100 feet in thickness.

Parts of the Simpson sandstones have the qualities requisite for manufacture of glass, the location of known glass-sand deposits being shown on Figure 1. Studies of texture and composition of these sands show that the grains are mostly very fine and that impurities are low. The coarser grains are rounded while the finer are angular, nearly all showing secondary enlargement. Figure 2 presents a summary of screen tests on forty-four samples, and the following analysis shows the average composition of the

[1] Joseph A. Taff, *Tishomingo Folio*, 1902, Folio 98, U. S. Geol. Survey, p. 3.

Figure 1.

OUTCROPS OF SIMPSON FORMATION IN OKLAHOMA

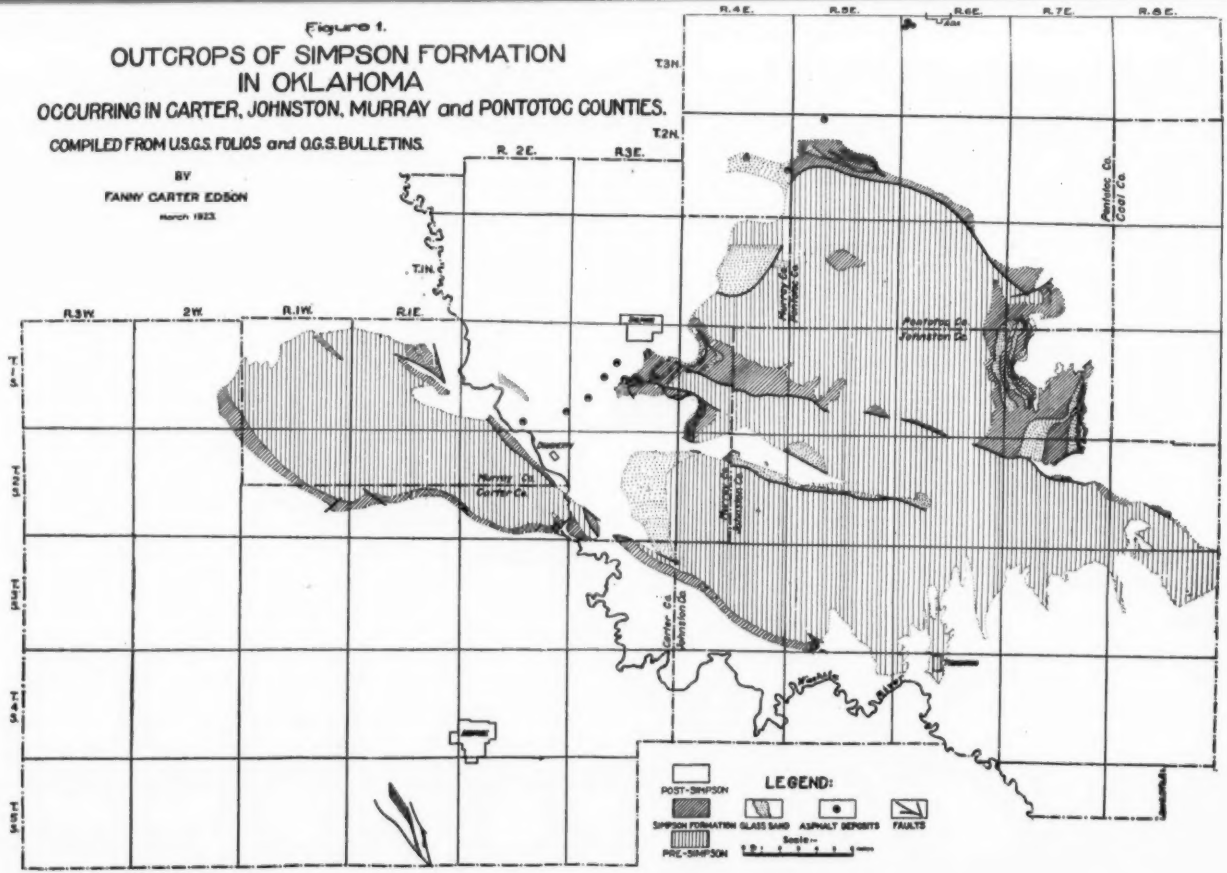
OCCURRING IN CARTER, JOHNSTON, MURRAY and PONTOTOC COUNTIES.

COMPILED FROM U.S.G.S. FOLIOS and O.G.S. BULLETINS.

BY

FANNY CARTER EDSON

March 1923.



samples: Fe_2O_3, 0.26; Al_2O_3, 0.33; CaO, 2.35; MgO, 0.05; SiO_2, 95.42; organic, 0.03.

Asphalt deposits occur at various horizons in the Simpson, the asphalt serving as a cement which holds the sand grains together. The location of known deposits is shown on Figure 1. The asphalt

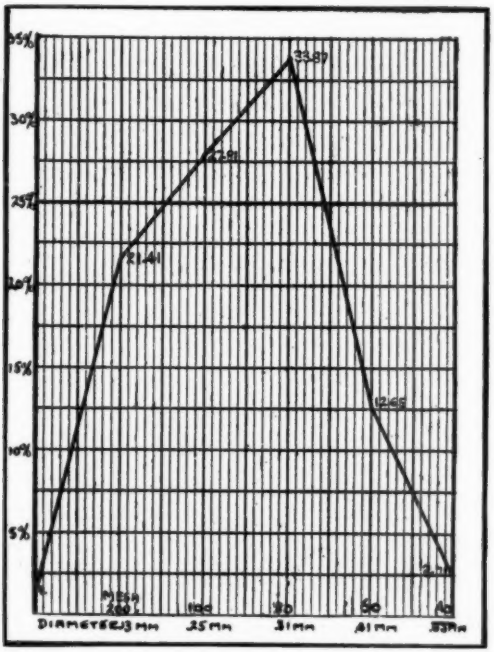


FIG. 2.—Average assortment curve showing size of grains. Forty-four curves averaged.

has apparently been formed by metamorphism of old oil pools, in which the volatile hydrocarbons have been driven off, leaving the asphaltic residue. The deposits show how widely petroleum of an asphaltic base was distributed through the older rocks of the Arbuckle region prior to their deformation and the erosion to oil-bearing levels which permitted escape of the more volatile portions

of the enormous petroleum deposits once stored in the sandstone and porous limestone.

In the Tahlequah quadrangle the Ordovician consists of the Burgen sandstone below and the Tyner shale above. The Burgen is a massive, fine-grained, light-brown sandstone, varying from a thin stratum to beds aggregating more than 100 feet in thickness. The lower Tyner is about 80 feet thick and is made up of green shale with thin sand beds; the middle Tyner is only 10 feet thick and consists of sandstone and cherty limestone; the upper Tyner is a coarsely crystalline fossiliferous limestone which closely resembles the Viola. Correlation of the Burgen and Tyner with the Ordovician type section based on fossil identifications is shown in Figure 3.

At the Simpson horizon in the Ouachita Mountains there is a non-fossiliferous formation known as the Womble equivalent.[1] In the absence of fossils, exact correlation cannot be made, but, because it consists almost entirely of sandstones and grits, the Womble apparently represents deposition in more shallow water than does the Simpson, and it may be inferred that there was here a new and abundant source of sand, possibly due to the rise of nearby land. If the Simpson occurs in the Wichita Mountains, it is entirely concealed by the red beds. A well in Sec. 7, T. 1 N., R. 3 E. encountered Simpson from 1,420 to 2,800 feet. The Simpson was here extremely variable in composition.

It is believed that the erosion surface at the top of the Arbuckle limestone may represent the beginning of St. Peter time. The textural characters of the formation are variable, brought about by the oscillating and shifting conditions of sedimentation during the time of marine Simpson deposition. The beds of pure white Simpson sand are evidently beach or near-shore deposits. It is believed that the silicious material was derived from the north, as is supposed to have been the case also for the St. Peter sandstone. The Simpson beds grade laterally from one type of sediment to another, but seem to have been laid down under marine conditions.

[1] C. W. Honess, "Geology of the Southern Ouachita Mountains of Oklahoma," *Okla. Geol. Survey, Bull. 32*, Part I.

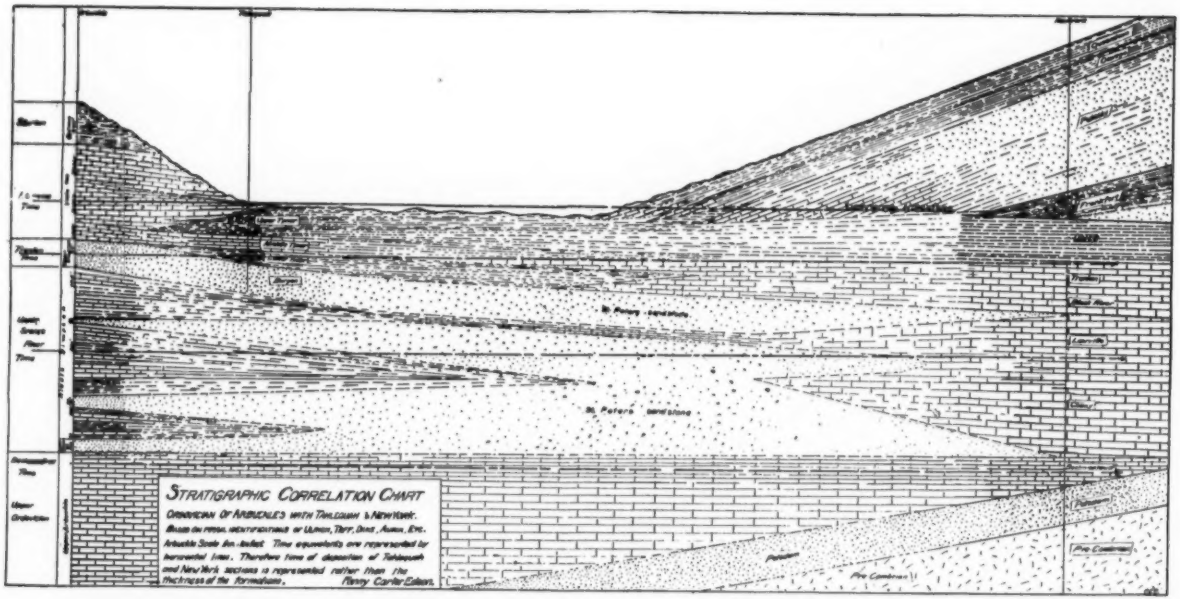

STRATIGRAPHIC CORRELATION CHART
ORDOVICIAN OF ARBUCKLES WITH TAHLEQUAH & NEW YORK.
Based on fossil identifications of Ulrich, Tarr, Dake, Aurin, Etc.
Arbuckle Scale 4in.=1mile. Time equivalents are represented by
horizontal lines. Therefore time of deposition of Tahlequah
and New York sections is represented rather than the
thickness of the formations.
Henry Carter Eaton.
St. Peters sandstone
Pre Cambrian

FIG. 3

Seventy-one Simpson fossils were named and described by L. E. Trout[1] in 1913, his list being as follows:

FOSSILS OF THE SIMPSON

Receptaculites sp. new *U*
Protarea vetusta *U*
Chaetetes lycoperdon *c U*
Stromatopora proutana *U*
Phylloporina sublaxa Ulrich
Arthroclema sp. ?
Strictopora fenestrata
Rhinidictya nicholsoni *U*
Pachydictya foliata *c*
Lingula cobourgensis *U*
Craniella ulrichi *r U*
Crania sp. new
Crania granulosa *U*
Pholidops trentonensis *r U*
Rafinesquina alternata
Rafinesquina minnesotensis *r*
Camarella varians *r L*
Camarotoechia pristina *L*
Strophomena incurvata *U*
Plectambonites sericea
Clitambonites multicostus *L*
Orthis tricenaria *r*
Orthis testudinaria
Orthis costalis *L*
Orthis (Dinorthis) deflectra *r U*
Orthis (?) holstoni *L*
Orthis acutiplicata
Plectorphis plicatella *r*
Dinorthis pectinella *r*
Hebertella bellarugosa *U*
Scenidium anthonense
Dalmanella perveta
Dalmanella pogonipensis *r L*
Triplecia ulrichi *U*
Siphonotreta sp. ?
Schizambon minnesotensis *r U*
Zygospira modesta
Zygospira nicolleti *r U*
Ctenodonta contracta *r*
Ctenodonta nasuta *r U*
Cyrtodonta sp. undet. *r L*
Clionychia lamellosa
Modiolopsis modiolaris *r L*
Eurymya plana *U*
Tetranota obsoleta *U*
Maclurites magnus *L*
Bucania hall
Lophospira perangulata *r*
Eccyliopterus vagrans *L*
Eccyliomphalus proclivis *r L*
Pterotheca attenuata
Orthoceras lesueuri *U*
Cameroceras proteiforme
Ampyx sp. *U*
Bathyurus schucherti *U*
Illaenus bayfieldi *r L*
Bumastus erastusi *L*
Platymetopus sp. near cucullus and bicoinis
Pliomerops nevadensis *L*
Platymetopus schmidti *U*
Vogdesia bearsi *L*
Leperditella macra *L*
Leperditia persimilis
Leperditia bivia *L*
Leperditia fabulites *c L*
Leperditia canadensis *c L*
Primitia sp. new *L*
Amygdalocystites billings
Glyptocystites billings
Platycystites sp. new *L*
Archaeocrinus sp. ?

[1] L. E. Trout, *The Geology and Paleontology of the Simpson Formation.* Thesis submitted for M.A. degree, University of Oklahoma, 1913.

r, rare; *c*, common; *U*, upper Simpson; *L*, lower Simpson.

DISCUSSION

ARTHUR E. BRAINERD: A well drilled northwest of center of Sec. 16, T. 4 N., R. 4 E. some 25 miles north of Sulphur showed typical green shale of the Simpson with Simpson fossils.

JOHN BARTRAM: The Simpson formation has been found in one well on the east end of the Wichita Mountains. This well, that of Barbour, *et al.*, in T. 4 N., R. 11 W., drilled through the Viola limestone and a little distance into typical Simpson green shale.

There are now three fields in southern Oklahoma definitely producing oil from the Simpson formation, Healdton, Hewitt, and Robberson. In Healdton three wells produce from the Simpson; in Hewitt one from the Simpson and one from the Viola limestone; and in the Robberson field several wells including the recent large gusher of Nelson Brothers. There are several Viola or Simpson (?) wells in the Brock or Crinerville field.

CHARLES T. KIRK: Mr. C. L. Dake has traced the St. Peter sandstone tentatively into Oklahoma. Has he or anyone done anything with the correlation of this sand by means of mineral content? Does he correlate this St. Peter-Tyner with the Simpson?

FANNY CARTER EDSON: In his published work Mr. Dake says that the St. Peter sandstone should not be extended to include that of the Simpson.

Further work, it appears to me, may show a double source for the material of the Simpson formation, one in the north and another in the south.

THE MONROE GAS FIELD, LOUISIANA

BEN K. STROUD AND FRED P. SHAYES
Shreveport, Louisiana

LOCATION

The Monroe gas field is situated in the parishes of Ouachita, Morehouse, and Union, Louisiana. The south end of the field lies about eight miles north of the city of Monroe, from which place the field takes its name.

SIZE OF FIELD

Until September, 1922, the proved area of the field embraced approximately 254 square miles and this figure has been used in all recent reports and estimates. About the middle of September, 1922, the Windsor Oil and Gas Company brought in their Pipes No. 1, $3\frac{3}{4}$ miles east of the nearest producing well (Sec. 18, T. 19 N., R. 6 E.) for about 200,000 cubic feet, open-flow capacity. This well, while itself comparatively unimportant, has increased the proved area to 300 square miles, making the Monroe gas field probably the largest in the United States.

The ultimate limits of the field in all directions are not yet known, but when the field is outlined definitely the total proved acreage will doubtless not be much in excess of 300 square miles. In a field of such immense size, it is not surprising to find a variation in thickness of gas rock, porosity of rock, and open-flow capacities.

HISTORY

R. E. Allison drilled the first well in the Monroe field in September, 1916, and abandoned it at a depth of 2,902 feet, after having cased off the gas and drilled into salt water. A few other wells were then drilled in the vicinity in search of oil, but it was not until the latter part of 1917 that any extensive drilling program was commenced, and the gas was first utilized for carbon black production.

GEOLOGY

The Monroe field occupies a position on the south end of an uplift similar, and roughly parallel to the Sabine Uplift. This uplift, known as the Ouachita Uplift, extends into Arkansas and is no doubt responsible for a great amount of the production of that state.

The surface rocks are of Recent age and are for the most part covered with a veneer of alluvium and re-worked material. So fas as known to the writers, there is practically no surface evidence of structure.

STRATIGRAPHY

Recent alluvium
Wilcox
Midway
Arkadelphia clays
Nacatoch sand (?)
Marlbrook marls (?)
Annona chalk
Brownstown marls
Eagle Ford, Blossom } Missing in several parts of the field
Woodbine

No systematic paleontological work has been done, and no results for the area published, so that it is impossible to correlate the formations above the Annona with respect to contacts and thickness. The Annona (a tongue of the Austin chalk), which carries the first and main gas pay and has been correlated definitely, is found at a depth ranging from 2,050 feet to 2,400 feet below the surface. In this area, the Annona is extremely thin and in many places produces gas throughout its entire thickness from 20 to 100 feet. Below the chalk, and in some wells immediately under it, are red shales, although some logs reveal an interval of a few hundred feet. As it is becoming an accepted theory that the red shales are of Woodbine age, or older, and inasmuch as the gas rock (Annona) is known to rest directly upon them in some cases, it is likely that an unconformity may exist, with the Eagle Ford entirely missing at least in some parts of the field. An example of the

proximity of the red shales to the Annona chalk may be seen in the La Del Fee No. 2 in Sec. 16, T. 19 N., R. 5 E. The chalk was found in this well from 2,185 to 2,210 feet with red shale and sand from 2,210 to 2,212 and gas rock again from 2,212 to 2,220, then white sandy lime to a total depth of 2,227 feet. This well blew red shale from the bottom for a considerable length of time.

In other parts of the field, notably in T. 21 N., R. 4 and 5 E. and in T. 20 N., R. 3 E., the red shales are deeper and the Eagle Ford, carrying the second gas rock, is present. Whether or not the second gas rock is uniformly present where the Eagle Ford exists cannot be answered until more deep wells have been drilled. The Texas Company which is drilling a deep test in Sec. 10, T. 22 N., R. 4 E., is now fishing at 3,458 feet. The gas rock is logged in this well from 2,090 to 2,146 feet. The log shows alternating rock, shale, gypsum, and lime to 2,329, where it was necessary to keep heavy mud circulating to prevent a blow-out. From this to the present depth, the log shows red shales alternating with lime, sand, and shale.

CHARACTER AND DESCRIPTION OF PAY SAND

The first pay sand is composed of sandy lime and in some places of pure chalk varying in compactness, hardness, and porosity and ranging in thickness from 10 to nearly 100 feet. A cross-section through the northern portion of the field made by H. C. Morris shows the gas rock thickest on the crest of the structure and thinning out on the eastern flank. Sections A-A and B-B accompanying this paper show the top of the first sand running east and west, and northwest and southeast. On account of the lack of wells drilled through the pay, it is impossible to show the thickness of the gas rock except in a few instances. However, it is probable that the gas rock is thinner toward the east and thicker toward the west off the uplift. The Annona chalk is known to have a thickness ranging from 250 to 300 feet near Shreveport, 100 miles west.

The second gas rock is found at an interval ranging from 198 feet to 432 feet below the top of the first pay. (See Table I.)

TABLE I

WELLS DRILLED THROUGH SECOND GAS ROCK

File No.	Company	Well No.	Sec. Twp. Range	Distance Drilled below Top First Pay	Top Second Gas Pay	Distance between Top First and Top Second	Production of Second Sand	Total Capacity of Well	Total Depth
23.....	Commercial Oil & Gas	Commerce No. 3	14–19–4	?	?	?	?	.....	2,921
58.....	LaFourche Oil & Gas Co.	Breece No. 1	27–18–5	176	?	?	?	.....	2,504
61.....	Morehouse Oil & Gas Co.	Newblock No. 1	33–22–5	224	2,489	223	30,000,000 Both sands	30,000,000	2,490
62.....	Morehouse Oil & Gas Co.	Newblock No. 2	33–22–5	232	2,488	226	.....	30,000,000	2,494
75.....	Morehouse Oil & Gas Co.	Grayling No. 1	7–22–4	300′	?	?	S.W.	1,000,000	2,430
91.....	Mountain Gulf	Grayling No. 1	39–20–5	1,457	.....	See below*	.....	.....	3,687
119.....	Progressive Oil & Gas Co.	Discovery Well	37–20–5	627	?	.....	.....	.....	2,902
162.....	Sterling Oil & Gas Co.	Crossett No. 1	45–21–5	200	2,400	170	.....	16,000,000	2,430
163.....	Sterling Oil & Gas Co.	Crossett No. 2	43–21–5	198	2,415	147	.....	3,000,000	2,430
164.....	Sterling Oil & Gas Co.	Freeland & Odom No. 1	20–21–5	315	?	259	.....	5,000,000	2,534
171.....	The Texas Company	Grayling No. 1	29–21–4	235	2,292	229	.....	25,000,000	2,298
179.....	The Texas Company	Vaughn No. 1	21–21–5	432	2,421	185	Dry	.....	2,668
178.....	The Texas Company	Tensas Delta No. 2	4–21–4	224	2,318	206	3,000,000	10,000,000	2,335
181.....	The Texas Company	Tensas Delta No. 3	10–22–4	1,368 Drilling	2,329	239	.....	.....	3,458
191.....	Union Power Co.	3,002	13–20–3	207	2,312	204	.....	10,000,000	2,315
193.....	Union Power Co.	3,005	3–20–3	274	?	?	.....	3,000,000	2,349
15.....	Atlas Oil Company	West Virginia No. 1	34–19–5	624	?	?	.....	500,000	2,838

* First sand reported at 2,250, 12,000,000; deep sand reported at 2,620 with 5,000,000 to 8,000,000.

Due to lack of sufficient wells drilled to the second gas sand, it is impossible to say anything definite in regard to its extent, average thickness, porosity, or content of gas. At the present time, the combined open-flow capacity of the three wells producing from the second gas sand amounts to 53,000,000 cubic feet per twenty-four hours.

POSSIBILITIES OF DEEP PAY

The possibilities for a pay still deeper than the so-called second gas rock are as yet problematical. So far, nine wells have been drilled in and around the Monroe gas field through both gas sands in search of oil, and of this number but three were well located on the structure. Results from these tests have so far been discouraging.

WATER

Nearly all of the wells in the Monroe gas field show small quantities of salt water when they are first opened and blown, but water conditions within the field are excellent and no wells, except a few having leaky water strings, letting in top water, show serious amounts of salt water. There is practically no danger from bottom waters anywhere on the fold. It is still rather early to make a positive statement regarding the edge-water limits for the entire field, but from the data available the edge-water zone may be fairly accurately located as being about the 2,200 foot sub-sea contour for the north and eastern flanks of the fold. Practically all of the wells drilled on, or below, this contour show typical edge water conditions.

CONTOUR MAP

When Bell and Cattell made their report on the Monroe gas field,[1] they mapped a fault of unknown extent running northeast and southwest through the southeast end of the field. This fault was based on the log of one well only, No. 204 (West Virginia-Florsheim No. 1). The fact that this area carried the highest gasoline content of any part of the field was taken as further evidence to mean that the gas originated from the so-called fault. Since that report was written other wells have been drilled in this vicinity which apparently disprove the presence of the fault, and for this reason, the log of the well in question has been regarded as having been inaccurately measured and no fault is shown on the accompanying contour map. (Figure 1.)

[1] H. W. Bell and R. A. Cattell, "The Monroe Gas Field, Louisiana," *Louisiana State Department of Conservation Bull 9*, 1921.

GASOLINE CONTENT

The zone of gasoline content follows a belt closely paralleling the contours on the eastern slope of the fold, becoming leaner toward the crest. It is also true that the gasoline content is becoming richer on the eastern slope, and that the gasoline content is increasing as the field declines in rock pressure. Figures substantiating these data cannot be published at the present time.

PRODUCTION AND USE OF GAS

The gas from the Monroe gas field is used almost entirely for the manufacture of carbon black, there being at the present time fourteen companies engaged in this enterprise. According to the report for the week ending March 9, 1923, the total consumption for the week was 1,230,587,000 cubic feet or 175,798,143 cubic feet per day. This withdrawal was from 88 wells giving a daily average of about 2,000,000 cubic feet per well. The total daily open flow for these 88 wells is 1,038,591,000 cubic feet.

At the present time the carbon black produced in the Monroe field runs approximately one million pounds per week and it is estimated that the yield of black for 1923, based on the present gas consumption plus the gas which will be used for the plants now in process of erection, will reach sixty-five million pounds.

The price paid for the black at the plants ranges from 10 to 20 cents per pound. Taking $12\frac{1}{2}$ cents per pound as an average for the field for the year 1923, the gross income to the carbon black manufacturers will reach over eight million dollars. This return is from a relatively small investment and low operation cost. The cost of producing carbon black is around $3\frac{1}{2}$ to 4 cents per pound.

Practically all of the carbon companies operate gasoline absorption plants in connection with the burner plants and derive a good revenue from the sales of gasoline. For this reason the area of the most wells and greatest withdrawal is in the southern part of the field and extends up the east side following the zone of richest gasoline content. As a result of this close spacing of gas wells and localized areas of greatest production, the rock pressure in these

portions is somewhat lower than the average for the entire 300 square miles. The open flow of later wells, however, is not affected, apart from an occasional well drilled into a tight place in the gas rock (Annona chalk).

The drilling record of March 10th, 1923, shows the following:

Dry holes	1
Deep tests (abandoned)	2
Deep tests (drilling)	1
Junked holes	5
Craters	1
Temporarily abandoned	2
Producing wells	144
Wells drilling	16
Total	171

Of the wells listed as producing, 56 are shut in and 88 are producing. The 88 wells have a daily open-flow capacity of 1,038,591,000 cubic feet.

The Monroe field is largely controlled by some half dozen companies, although there are many small owners controlling from $\frac{5}{10}$ per cent (700–800 acres) to 3 per cent (6,000–8,000 acres) each.

The last legislative assembly enacted as law Act 91, under which the Department of Conservation has been issuing to bona fide land or lease owners, permits for the erection of carbon plants. In addition to the fourteen companies now actually making carbon, there have been nineteen permits issued which call for an additional daily 212,000,000 cubic feet of gas. In other words, if all these permits are exercised, the total withdrawal of gas by all companies from the field will be 378,000,000 cubic feet per day or 136,000,000,000 cubic feet per year. It is doubtful, however, if all the proposed plants will be built and the total daily consumption will probably not run much over 200,000,000 cubic feet per day. Fully 98 per cent of this gas will go to carbon black, as there is very little industrial business in the area. The Bastrop pulp mill uses about 2,000,000 cubic feet per day, but there are no other large industrial enterprises now operating.

For the year 1922, the following gas was taken from the Monroe gas field.

	Cubic Feet
January	2,164,517,529
February	3,906,057,989
March	3,237,174,000
April	3,087,690,000
May	3,888,165,000
June	3,335,188,000
July	3,309,944,000
August	4,151,927,000
September	3,329,362,000
October	3,475,388,000
November	4,720,033,000
December	3,866,007,000
	42,491,423,518

The production of the field year by year since its inception is as follows:

	Cubic Feet (Actually measured)
1918	2,310,443,898
1919	7,075,060,088
1920	20,300,502,730
1921	33,358,327,162
1922	42,491,423,518
	105,535,757,396

SIZE OF GAS RESERVOIR AND PROBABLE LIFE OF THE FIELD

There are many difficulties in arriving at the amount of gas in a field. Average thickness of the producing horizon, porosity of the rock, and amount of gas already withdrawn are some of the factors to be considered. Any figures must be based on available data which at best give only an approximation. For this particular field, the enormous waste from craters and bad wells which took place previous to 1921 has been estimated by the Department of Conservation at around twenty billion cubic feet. This estimate is undoubtedly conservative.

There have been no further tests made on the porosity of the gas rock which are available to the writers, so the figure .23, used by Bell and Cattell,[1] is employed for the entire field.

[1] *Op. cit.*

Owing to the concentration of production in certain areas of the field, the rock pressure has declined more in these areas than in others. Figure 2 shows these low pressure areas fairly well. For the following calculations of gas volume, the field has been divided into three zones, averaging in rock pressure, 1,032, 953, and 849 pounds, respectively. Several wells which show a rock pressure much lower than the minimum considered, are included in each of these areas. These have been disregarded since the decrease is due mostly to leaking casing. The porosity of .23 is used for each zone, but the thickness of the productive horizon has been reduced to 20 feet for the third zone, 25 feet being used for the first two zones.

Zone 1. 166 sq. mi. × 5,280² × 25 ft. × .23 porosity = 26,680,000,000
Zone 2. 88 sq. mi. × 5,280² × 25 ft. × .23 porosity = 14,043,000,000
Zone 3. 44 sq. mi. × 5,280² × 20 ft. × .23 porosity = 8,060,000,000

48,783,000,000

cubic feet of gas for the entire field at 1,050 lbs. rock pressure.

$$\frac{48{,}783{,}000{,}000 \times 1{,}050 + 14.7}{.5 + 14.7} = 3{,}420{,}000{,}000{,}000$$ cubic feet of gas in reservoir at 8 ounces above atmospheric pressure. Assuming that 50 per cent of this amount is recoverable under ideal conditions, there is a total ultimate yield of 1,710,000,000,000 cubic feet or about 8,900,000 cubic feet per acre.

Various estimates ranging from 1,200 to 1,050 pounds have been made on the initial rock pressure of the field. The pressure which most of the operators agree upon, and which checks closely with the static head, is 1,050 pounds. The decrease in pressure within the three zones would indicate that

$$\frac{18 \times 935{,}000{,}000{,}000 \text{ cu. ft. @ 8 oz.}}{1050 + 14.7} = 16{,}825{,}000{,}000 \text{ cu. ft.}$$

$$\frac{97 \times 492{,}500{,}000{,}000 \text{ cu. ft. @ 8 oz.}}{1050 + 14.7} = 44{,}800{,}000{,}000 \text{ cu. ft.}$$

$$\frac{201 \times 282{,}500{,}000{,}000 \text{ cu. ft. @ 8 oz.}}{1050 + 14.7} = 57{,}100{,}000{,}000 \text{ cu. ft.}$$

118,725,000,000 cu. ft.

of gas have already been withdrawn from the reservoir. Taking this total and deducting 105,536,000,000 cubic feet of gas actually

measured, there is unaccounted for 13,189,000,000 cubic feet. If two-thirds of the 1,710,000,000,000 cubic feet are actually to be recovered of which 118,725,000,000 cubic feet have already been taken out, there still remains 1,021,275,000,000 cubic feet, or sufficient to last for fourteen years at a daily withdrawal of 200,000,000 cubic feet.

All gas fields are overestimated in their early age and the gas is allowed to go to waste under this false impression. Further, such factors as waste from wild and uncontrolled wells, underground leakage, and the encroachment of salt water, all take their toll from the recoverable gas. Salt water apparently does not always drive the gas in a body to the higher parts of the fold. Instead of collecting and conserving the gas, salt water often drowns it out, or forces it to positions where its ultimate recovery may be uncertain. There is evidence of this action in the other Louisiana gas fields. The life of a field is in direct ratio to the care and attention given it by the driller and operator in the prevention of waste, and protection from water encroachment. The Monroe gas field is being drawn upon at an alarming rate.

GEOLOGICAL NOTES

REPORTED OIL STRIKES IN HANNA BASIN AND RED DESERT, WYOMING

Late in June it was reported that the Producers and Refiners Corporation had struck oil at a depth of 655 feet in their test on the Simpson Ridge anticline in the Hanna Basin of Wyoming. Simpson Ridge is located 15 miles southwest of Medicine Bow in Carbon County, Wyoming. It is a long, narrow anticlinal fold trending northeast. Its flanks dip from 25° to 35° but the closure is slight for there is little reversal at the southwest end where it joins the general uplift that produces Elk Mountain.

Along the crest of the anticline the Mesaverde formation of Upper Cretaceous age crops out. Underlying the Mesaverde is the Steele shale, and the oil was found in a sandstone in a transition zone between the Mesaverde and the Steele shale. It corresponds roughly in position to the Shannon sandstone, best known as the "Rimrock at Salt Creek." However the Shannon is not typically developed in southern Wyoming. There was very little oil in the sand and the well showed water soon after the strike. By this time it has probably been abandoned. The strike does not indicate a new oil-yielding horizon, for small quantities of oil have previously been found at this horizon. It is to be expected that in very sharp folds such as Simpson Ridge the oil will be found concentrated at the very crest of the anticline, as it was in this instance.

The objectives of the well were the Wall Creek and Dakota sandstones, which may lie about 4,000 and 5,300 feet respectively beneath the surface. There is some question as to the thickness of the Steele shale in this vicinity. The Producers and Refiners Corporation took the chance that the shale was less than 4,500 feet thick, although a well drilled by the Kasoming Oil Company four miles south of Simpson Ridge some years ago started in the Steele shale and had not gone through it at 4,225 feet. It is possible that the apparent thickness of the Steele shale in the Kasoming well was due to faults or steep dips that did not manifest themselves at the surface. The Niobrara and Carlile shales which lie below the Steele shale must be penetrated before the Wall Creek will be reached.

The Sage Creek Petroleum Company, drilling on the Buffalo anticline in the Red Desert country of southern Wyoming, brought in a gasser late in June, which was estimated to have a capacity of 35,000,000 cubic feet per day. Buffalo Basin dome is an anticlinal fold on the south flank of the Sweetwater uplift, bearing much the same relation to the uplift as does the Lost Soldier dome.

Much of the country surrounding the dome is covered with freshwater sediments of Tertiary age, which lie unconformably on the Cretaceous. However, on the anticline enough of the Upper Cretaceous is exposed to show that an anticline is present, although not enough to show its size, steepness of flanks, closure, etc. The well, which is located on the crest of the fold, reached the upper Wall Creek sandstone at about 600 feet. The gas was found in the lower Wall Creek sandstone at about 900 feet.

The gas strike indicates that the anticline has considerable closure. Also that good production of gas or oil may be expected in the Dakota sandstone which is probably about 1,300 feet below the top of the upper Wall Creek sandstone. However, the Buffalo anticline is so far from transportation and markets that its development will very likely be postponed to the future.

—*From notes by* E. W. KRAMPERT.

VOLCANIC ASH IN NORTH CANADIAN VALLEY, OKLAHOMA

In the valley of the North Canadian River in Okfuskee County, Oklahoma, the writer has recently observed two exposures of volcanic ash beneath the alluvial deposits of unconsolidated sand and loam that spread over the uplands bordering the present course of the river.

One of these exposures is in the southwest quarter section 25, T. 10 N., R. 9 E., and the other in the southeast quarter section 19, T. 10 N., R. 10 E. At both places the ash has been mined to some extent and used in Okmulgee and Tulsa as a filler in the paint industry. It is of light gravity, white to brown in color and the compound microscope shows it to be made up of exceedingly fine-grained, clear, clean, elongated, angular, glistening particles of amorphous, glassy material. It is exceedingly free from extraneous matter; so much so, in fact, that it is difficult to conceive of the nature of its transportation and deposit. There is little doubt that it originated in the Rocky Mountain province, whence it was transported to its present site. It represents, in fact, the first

material brought down by the river, for it lies unconformably on Pennsylvanian rocks and is in turn covered unconformably by the gravel, clay, and sand of the early Pleistocene, which spreads back from the present river valley proper and covers some of the adjacent higher hills up to altitudes of 75 feet above the present bottom terrace of the North Canadian. It is probable that the ash beds are late Tertiary in age and are contemporaneous with the white sandy clay deposit beneath the loams and gravel of the Arkansas River valley shown in typical exposures in the vicinity of Broken Arrow in Tulsa County, Oklahoma. This clay rests directly on the Pennsylvanian beds at the outer margin of the Pleistocene cover and dips toward the river beneath the gravel, sand, and loam which was brought down at the breaking up of the period of continental glaciation in the Rocky Mountains. The writer believes that the rivers which cross Oklahoma from west to east were "spill ways" from the late Tertiary basins of the western Great Plains district, and that the volcanic ash and white clay beds at the very bottom of the alluvial deposits are probably Pliocene in age, and are due to volcanic activity in the Rocky Mountain region during Pliocene time when these streams found their approximate present courses.

The stratigraphic section in the southeast quarter section 19, T. 10 N., R. 10 E., on lands belonging to T. S. Palmer and T. E. Stanley is as follows:

	Feet	Inches
Red clay	5	
Gravel bed		6
(Unconformity)		
Volcanic ash, brown, hard, consolidated with some clay	3	
Volcanic ash, brown, thinly stratified	2	
Volcanic ash, white, soft, pure	3	
Volcanic ash, white, partly concealed	10	
(Unconformity)		
Pennsylvanian sandstone and shale		

The gravel bed consists of loose gravel at the base of, and is really a part of, the red clay deposit. The pebbles in the gravel range in size from $\frac{1}{4}$ inch to 2 inches diameter in this locality. In other localities in the same district, however, much larger pebbles, some of them as much as 5 inches in diameter, are found at this same horizon, and the deposit locally increases to several feet in thickness. The pebbles are well rounded and water-worn and include white quartz, brown and red chert, brown and white hard sandstone, ferruginous sandstone, black limonite

(probably resulting from weathered pyrites from older clastic rocks) quartzite, granite, and occasional representatives of other types of the crystalline rocks. The clay and gravel bed lies irregularly over the ash bed with distinct unconformity. The strata of the ash bed are approximately horizontal, whereas the clay and gravel bed dips northwestward at the rate of 2 feet in 150 feet. The top part of the ash bed is impure and is consolidated so that it may be mistaken for sandstone unless closely inspected. It is distinctly jointed, one set of joints running north 65 E. by South 65 W. and the other North 35 W. by South 35 E. This jointing is probably a local condition, but closely agrees with jointing in the Pennsylvanian rocks below.

A sample of the ash was analyzed for the writer by Ledoux & Company, New York, with the following result:

ANALYSIS OF ASH

	Per Cent
Ignition loss (water)	6.3
Silica	71.5
Alumina and iron oxide	15.9
	93.7
Loss chiefly lime and alkalies (potash and soda)	6.3
	100.00

The microscope shows plainly that no infusoria or diatoms are present and that the material is plainly volcanic ash. It is equally evident from a study of the deposits on the ground that it is stratified and undoubtedly deposited by settling in water. May we not consistently assume that the drainage of the North Canadian at that time was poorly established so that there were probably numerous lakes and areas of quiet water along its course in which material of this character would find an opportunity to settle out? This material is sufficiently light so that when associated with more or less colloidal solutions it would be borne in suspension by moving water for great distances. In fact, it is similar material in the Arkansas and other rivers at the present time which interferes to a great extent with the purification of water for domestic use in the cities along the course of these streams which head back in the Rocky Mountain region.

JAMES H. GARDNER

REVIEWS AND NEW PUBLICATIONS

Les Gisements de Petrole. By JEAN CHAUTARD. Paris: Octave Doin, 8 Place de l'Odeon. Price, F. 15.20.

The increasing demands of France for oil products have led to a growing interest on the part of the French people in the scientific side of the petroleum industry. Yearly the need for more and more oil is becoming a tremendous economic problem for France, since practically the entire supply for that country must at present be imported. Leading men in France are doing all they can to stimulate greater development of the resources within their own boundaries, and to this end Jean Chautard has made a valuable contribution in his recent excellent handbook on petroleum geology. For several years this author has been devoted to problems and questions of oil geology and exploration, and he has written some noteworthy papers along this line. No more capable or better-read author could have been chosen by the director of the Library of Applied Geology and Mineralogy to write this first comprehensive outline of oil geology for the French-reading public.

This publication is very concise but clearly written and quite complete in its scope, and it is similar in its general composition to some of our American handbooks that outline this subject. To readers desirous of delving more deeply into the various phases of the subject, he introduces a large amount of available literature as a bibliography at the end of the book, and this portion is one of the most interesting and valuable parts of this new contribution. A number of noteworthy references in Chautard's list have never appeared in any of our American publications, and this handbook may be highly recommended to petroleum geologists for the value of this bibliography alone. It is to be regretted that the quality of the paper and printing is so poor and that the illustrations have not been better reproduced. In general the maps and sections are too small and contain insufficient detail. But as it is designed primarily to serve as a guide, this feature is quite in harmony with its purpose.

The purpose of the book, as explained in its Preface, is twofold: first, to present concisely the present-day ideas and facts regarding the formation and accumulation of oil, the kinds of deposits in various parts of the world, and the methods of exploiting deposits; secondly, to arouse his countrymen to greater interest in the subject with the hope that native Frenchmen may attain greater prominence in this industry and develop the possible petroleum resources of France.

Chapter I deals with the definition, the character, and the physical and chemical properties of the various kinds of petroleum, natural gas, and bitumens.

Chapter II is entitled "Origin of Petroleum," and here the inorganic and organic theories are presented and weighed in a manner similar to discussions in our own publications. His acceptance of the probable organic origin of petroleum is supported by the description of the conditions of sedimentation that favor accumulation of organic matter, conditions and process of bituminization, mother formations, fossils, and geology of oil deposits in general as evidence of the organic theory. Chapter III handles in logical order the factors and forces involved in the accumulation and concentration of petroleum into commercial deposits, effects of erosion upon deposits, effects of commercial exploitation of a deposit, and the destruction of a deposit by water invasion. Chapter IV presents both the chronologic classification of oil deposits accompanied by the names of the corresponding oil-bearing regions of the world for each geologic period and the structural classifications of Professor L. Mrazec (director of Geological Survey of Roumania) and of F. G. Clapp. This chapter contains some especially interesting matter that will be presented more fully at the end of the review.

In Chapter V the author describes briefly each of the oil-bearing areas of the world and presents the essential features of interest in each place; a number of excellent and well-chosen maps and stratigraphic and structure sections accompany these descriptions. In Chapter VI Chautard applies geologic principles to field-exploration methods. He describes numerous surface indications of oil deposits and discusses briefly the significance of each; he points out especially the importance of maps and both stratigraphic and structure sections, the value of water analyses, and favorable indications that may appear while testing the area with a drill. At the end of the chapter a few pages are devoted to investigations now going on in France, in French colonies, and in the protectorates of north Africa. He expresses no great optimism regarding the results of these researches outside France, except perhaps in Madagascar. Chapter VII gives very briefly the main features in the exploitation of oil deposits; systems of drilling, tanks, pipelines, and other necessary equipment are described. At the end of the chapter a folded insert shows production statistics in American barrels for all countries from 1857 to 1920.

The last chapter states in a few pages the leading economic problems in the petroleum industry of the world. The author points out the rapidly growing power of petroleum throughout the world and calls it the "imperialism of petroleum." He sees the American hemisphere, through its production of 85 per cent of the world's total, fast becoming the master of destinies; he regrets that the division of national ownership is not more nearly equal and predicts only cataclysmic results in the present situation. England's future appears more optimistic considering her chances of production in new and vast concessions in the East. France, on the other hand, has only the small production of Alsace and Algeria. However, regarding this situation for France, no blame is cast upon, or criticism made of, any influence outside France herself. A mining law passed in 1910 by the French government has

been a great obstacle to developments on French soil, and the reluctance of French capitalists to risk money in oil ventures in France is greatly deplored. Monsieur Chautard pleads fervidly, therefore, for a modification of these ancient laws and urges the French people to rise to the needs of their country by developing to the limit the oil resources that may lie within the boundaries of France herself, instead of devoting so much energy to investigations in the colonies and protectorates. The French government is further invoked to aid in such researches for deposits in France, as oil found there remains there, and what is found in the colonies and protectorates is not easy to claim for French consumption and may be lost to France through exportations to other lands.

In considering the future he wonders if the startlingly rapid increase in consumption will reach so high a figure that the world's natural resources will become insufficient and finally exhausted. From our scientific knowledge of oil deposits and histories of old fields, Chautard fears that the near future will bring serious problems of supply and demand. He estimates that the world's reserve ranges from 2,000,000,000 to 10,000,000,000 metric tons. At the present rate of consumption (70,000,000 tons yearly) we can expect the end of the petroleum supply from 30 to 150 years hence, but it is hoped that the great advances in our scientific knowledge of oil problems may meet the requirements of future years.

More and more the oil fraternity is recognizing the importance to the commercial side of the industry of better understanding of the forces operating to distort the earth's crust, and in this connection the concepts and observations of Professor Louis Mrazec in the domain of tectonic geology have been well received by most European geologists. Inasmuch as the only recognition of his concept of diapirism and diapir folds in the literature of our language is found in a paper by Sherburne Rogers, "Origin of the Gulf Coast Salt Domes" (*Economic Geology*, XIII [Sept., 1918], No. 6) and a very brief reference by Dr. David T. Day in his almost exhaustive treatise on petroleum geology, it seems timely to introduce here the interesting subject as presented more comprehensively by Chautard.

As long ago as 1906 Professor Mrazec wrote his first paper describing certain abnormal folds in Roumania as a new type, which he termed the "diapir fold," or a fold with an upward-piercing core. Since then he has written, in French, considerably in detail on the subject of diapirism, and has found this interpretation applicable to many folds in several parts of the world. It was during his visit to the States early in 1918 that he found evidence of diapirism in the salt domes of the Gulf coast, in certain abnormal folds in California, and in Wyoming.

In Chapter IV of Chautard's handbook the author presents Mrazec's classification of oil deposits according to types of structure, and since he has concisely presented the essential features of the concept, a direct translation seems most desirable.

STRUCTURAL CLASSIFICATION OF LOUIS MRAZEC

Group I.—Deposits of autochtonic areas only slightly folded with large and gently folded anticlines in which the concentration of the oil has progressed slowly in the course of geologic periods; the Paleozoic deposits of North America and of Russia belong here, and in this category are included the domes, monoclines, flexures, etc.

Group II.—Deposits in areas of normal structure in which the successive strata are practically parallel.

Group III.—Deposits in autochtonic areas with diapir folds. In the folds with piercing cores, or diapir folds, the cores of the anticlines have been thrust upward, piercing the younger strata lying next to the core and also successively adjacent strata. The simplest example is an anticline in which the beds of the core are steeply inclined, whereas the overlying beds approach more and more a horizontal position. In other examples the core may pierce all or part of the beds up to the roof symmetrically or unsymmetrically; furthermore, the core may even be overthrust and lying upon one of the flanks of the fold; in the extreme relationship the core lies on the flank either connected with the underlying upthrust core or detached from it. [According to Mrazec, a diapir fold comprises three elements: the core, the pierced strata, and the roof.]

The areas of diapir folds are characterized by outcrops of old strata, generally considerably disturbed, in the midst of very young and slightly disturbed formations. [Mrazec has recognized several types of diapir folds, shown in Fig. 1.] In types 1 and 2 the beds of the core are not actually pierced through, but the overlying strata are more or less foliated or schistose due to the stretching near the axis of symmetry of the arch. Several structures in the Caucasus, Dutch East Indies, and Roumania belong here.

In types 3 and 4 the core is bent over and compresses the sides of the arch and intermediate strata; these types of folds are common in the Carpathians of Roumania, in the Caucasus (Grosny, Taman), the Cretaceous deposits of Louisiana, Texas, and Wyoming (Powder River dome), and in certain areas bearing traces of oil in Algeria.

In type 5 the folding of the beds in the core are not conformable with those in the arch, but the core does not pierce the arch.

In type 6 the core pierces the arch laterally and rests on one of its flanks; this type is common in Roumania.

In type 7 the core pierces the arch normally and presses out fanlike upon its flanks; this type is represented in the salt domes of the Carpathians, in certain deposits of Germany, Texas, and Louisiana. According to Mrazec in these fanlike or mushroom-shaped folds the core will be more or less squeezed by the pressure due to the resistance of the pierced beds and to the later subsidence of these beds.

In type 8 we find represented under a slightly undulating roof the existence of two diapir anticlines separated by a synclinal trough; this example illustrates rather special features of sharp anticlines in areas of diapir folding.

In the regions characterized by diapir folds, the deposits are generally located near the alignment of piercing cores or lines of compression; this localization is easily explained.

Group IV.—The deposits in areas of overthrust are closely related to the deposits in diapir folds and may be regarded as the extreme limit of the diapir fold. The deposits of this group spring either from rocks in the overthrust or from the mother rocks of the autochtone; the distinction between these origins

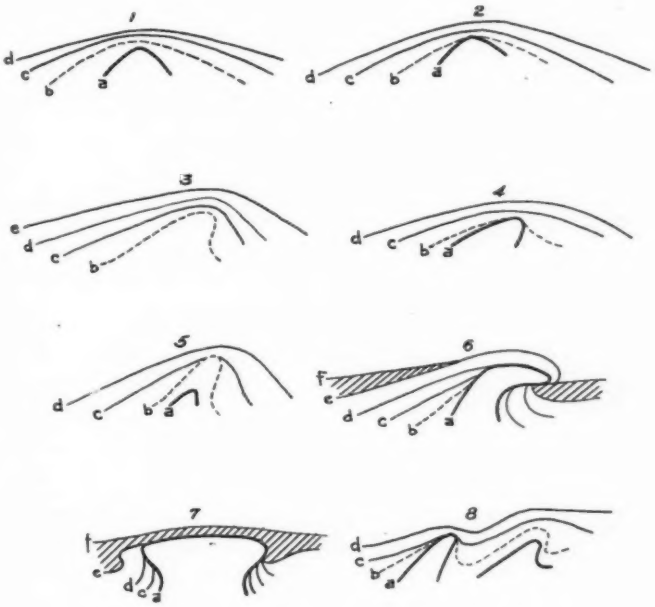


FIG. 1.—Principal types of diapir folds according to Mrazec

is essential in the study of, and search for, oil deposits. The leading deposits in overthrusts are those of Galicia and Roumania, India, and California; certain probable petroliferous areas of Morocco fall also into this group.

It is to be regretted that the numerous and enlightening papers by so eminent an authority as Professor Mrazec in his diligent study first of the oil deposits of Roumania and the Carpathians and later in North America and other countries, have not been translated and presented to English-reading geologists. The fundamentals of diapirism are by no means lacking in our

literature, but the features of this sort of folding have so far been not assembled so neatly into a type as Mrazec has presented them. It hardly seems that we can do better than to adopt his term for this type, since it is so well established in foreign literature. The idea of diapirism is by no means a theory but a proved fact, substantiated by careful observations. Though this idea alone may not be wholly adequate in the interpretation of our salt domes and other abnormal folds, no doubt it is an essential conception that we ought better to understand.

HELEN PLUMMER

Das Erdöl und seine Verwandten. By HANS HÖFER-HEIMHALT. Braunschweig: Friedr. Vieweg & Son, Publishers, 1922, Price $3.20.

Hans Höfer, well known for his handbooks on petroleum and his studies on the origin of oil in co-operation with the chemist Engler, one of the early promulgators of the so-called "anticlinal theory" of oil accumulation, has recently published the fourth edition of *Das Erdöl und seine Verwandten*. As eleven years had elapsed between the third and fourth editions, years of tremendous development in the petroleum industry, the book has changed considerably.

In an introductory chapter of four pages a classification of the different natural hydrocarbons is given, together with the names used in different countries.

The second chapter of 37 pages treats the history of oil development in the different parts of the world.

Chapters III and IV, of 31 and 88 pages respectively, are devoted to the physical and chemical properties of petroleum and the other hydrocarbons.

"Occurrence," discussed in chapter V, 75 pages, deals with primary and secondary deposits, migration of oil, structure of oil and gas fields including a discussion of the anticlinal theory, relations between coal and oil and salt and oil, oil field waters, earth temperatures in oil areas, effects of earthquakes on oil wells, dry and wet gas, gushers, mud volcanoes, occurrence of ozokerite and asphalt. A list of occurrences of hydrocarbons in the different formations from Cambrian to Recent is given.

In chapter VI, on "Origin," 95 pages, Höfer cites and refutes the different inorganic hypotheses and then discusses the different possibilities of formation of oil and gas from organic sources from a chemical and geological point of view. He comes to the conclusion that oil is formed from organic fatty substances, provided by carcasses of all kinds of animals of the sea and also of some plants of low order like diatoms (Monterey shale in California), which consist of a large percentage of fats. These organisms died and were deposited in large numbers in shallow water and soon covered up. Decomposi-

tion set in, possibly started by bacteria. Albumin substances decaying first would form mostly gases, which in part would escape. Nitrogen is abundant in certain natural gases. Carbon dioxide would dissolve lime shells, corals, etc., thus explaining the scarcity of fossils in most oil sands. The fatty substances are more easily preserved, especially under salt water, and withstand destruction until sufficiently covered. Laboratory tests show that they can be turned into petroleum by heat and pressure. In nature the pressure is supplied by deposition of younger formations and eventually by mountain building forces. The increased temperature conforming to the depth, eventually increased by friction due to orogenetic movements and heat originated through the process of decomposition are deemed sufficient, especially if the time is practically unlimited. Different composition of the oil as observed in different fields is more largely due to differences in temperature and pressure during the forming process than to differences in the primary material. Höfer thinks that most of the oil has been formed in the strata in which it is found today; that is, in the oil sands and not in the adjacent shales, though he admits exceptions, such as the Monterey shale, which is more porous than an ordinary clay shale. Where the containing formation was porous, gas, oil, and water in it separated according to their specific gravity, thus forming the well-known accumulations on anticlines. Most of the oil deposits are primary. Secondary deposits due to migration from one formation into another occur only in crevices or in porous strata connected by crevices with the primary deposit. Some may not agree with all the details of Höfer's explanation, but all who intend to study the formation of crude oil would do well to familiarize themselves first with Höfer's work.

Chapter VII, 17 pages, explains how to locate oil pools, especially in virgin territory, and chapter VIII gives production tables to and including the year 1920.

The book contains a large amount of information, partly Höfer's own observations, partly quotations from other authors. Unfortunately the important facts are not always given sufficient predominance over unimportant ones. The almost dominant importance in the petroleum industry of the Mid-Continent field of the United States would hardly appear from the book, except, perhaps, for the statistics in the last chapter. A reader not acquainted with the facts might get the impression that the carboniferous oil deposits of Oklahoma and Alabama are of about the same importance (p. 235).

The book would be much more valuable if it were illustrated more profusely. Especially geological and production maps and structural cross-sections of different producing areas would help greatly. Every petroleum geologist who is sufficiently versed in German will greatly benefit from studying the new edition of *Das Erdöl*.

EDWARD BLOESCH

Water Troubles in the Russian Oil Fields. Transactions of the Geological Section of the First All-Russian Congress of Oil Operators. Edition of the Council of Petroleum Industry, Volume III. For July and August, 1921.

A number of papers dealing with water conditions in certain of the Russian oil fields appeared in the above publication. They should be of interest to any student of the interrelations of oil and water, and are given a general interest at the present time by the entry of American companies into the Baku district where certain of these phenomena must be recognized and combatted. Among the more interesting of these papers are:

Underground Waters in the Baku Oil Fields. By D. GOLUBIATNIKOFF. The underground waters of the Baku districts are principally sodium chloride brines containing almost no sulphates. As a rule their concentration is in inverse proportion to their stratigraphic depth. Waters encountered in an oil well may come from the oil sand, from overlying strata, or they may rise along joint planes from lower levels. The source of water in a well may be ascertained by geothermic observation. If the temperature of a water agrees with the temperature at the bottom of the well, calculated by the thermal gradient of the area in which the well is situated, it came from the oil sand. If the temperature is lower it came from a stratum closer to the surface, and if higher, it rose from lower levels.

Encroachment of Waters in the Baku District and Methods of Prevention. By M. ABRAMOVITCH, Chief of the "Aznepht" (Baku) Geological Survey. The study of encroachment of water upon producing areas should begin with investigations concerning the source of underground water and its influence upon the flow of water in a well. All wells in the Baku district are now being systematically tested in order to obtain this fundamental information. Unquestionably water sands should be divided into two classes, primary or sands that never contained any oil, and secondary or water-logged sands. The difference in the rate of encroachment of water upon various localities depends upon the difference in the rate of oil production and the percentage of water in the fluid yielded. These data have been determined for each locality and are embodied in seven tables appended to the paper. In all wells now being drilled every effort is being made to exclude the water. Wells unfit for further production or that menace the oil bearing strata with water flooding should be abandoned.

Invasion by Water of the Balakhany Oil-bearing Horizons. By I. SAMOILOFF. The invasion of the upper oil-bearing sands of the Balakhany field by water need raise no apprehensions that the water trouble will spread. Tables appended to the paper contain approximate calculations relating to water encroachment in the field. Encroachment thus far is on a small scale and is scarcely noticeable except in the fourth and fifth horizons. This statement, however, does not apply to the deeper Kirmaki Series, which has been invaded by waters from the thick group of sands that lie between it and the upper oil-

bearing strata. Many of the wells that have penetrated the argillaceous sandy roof of the Kirmaki Series have had to be shut down because water from overlying strata found its way into the bottom of the well. The problem is so serious that all wells from which water enters the Kirmaki Series may have to be abandoned.

Water Troubles in the Sabuntchi District. By MR. APRESOFF. This paper deals with the stratigraphy of the eight water bearing sands in the Sabuntchi District, and contains general suggestions for the prevention of water trouble in various localities of the district.

A Few Remarks in Connection with Invasion of Old Areas by 4° Water. By J. GAVRILOFF. The decline of oil production in the Balakhany-Sabuntchi-Romany District which began in 1901 is due not merely to the natural depletion of the producing strata, but also to invasion by 4° water which rises in wells that were drilled below the fifth oil-bearing horizon. The natural decline in production can be compensated only by working deeper levels, particularly the Kirmaki Series. American rotary drilling methods should be introduced and the old bore holes which permit water to enter the Kirmaki Series should be abandoned.

Water Conditions in the Binagady Producing Area. By S. R. ZUBER. So far the oil-bearing strata of the Binagady producing area have not been affected by the water from the thick sands lying between the upper and lower oil-bearing horizons. Most of the water that penetrates the oil-bearing strata gains access through casing that was damaged by sandy oil in flowing wells which have been active over long periods of time. Water troubles of this kind in the present producing area are purely local and only affect individual wells without spreading to others.

The Bibi-Eybat Water-bearing Strata. By D. GALUBIATNIKOFF. This paper includes a discussion of the stratigraphy of the Bibi-Eybat water sands and a brief description of the nature of the water produced by them. These waters are of vadose origin and invade the producing sands from the Yasamal Valley and Atashka District.

The Geological Conditions Affecting Production in the Bibi-Eybat Area in 1922. By S. KAVALEVSKI. In discussing the geologic conditions relating to oil production in the Bibi-Eybat area, Mr. Kavalevski deals incidentally with Bibi-Eybat waters. The main bulk of these waters (up to 80 per cent) comes from the succession of water-bearing sands known as the 12th and 13th series. The rate of flow of these waters from the flanks of the flexure toward the area under exploitation is at present rather rapid, and it has been found that the most efficient way to shut them off is by means of compressors. In addition to the forty more or less up-to-date compressors already available in the district, not less than forty powerful plants should be installed for carrying on this work.

Invasion by Water of Oil-bearing Strata in the Baku and Grozny Districts. (Paper read before the general meeting of the First All-Russian Congress of Oil

Operators.) By I. GOUBKIN. The question of water trouble in the Baku and Grozny oil fields can best be dealt with under two heads: (1) Water trouble prior to the nationalization of oil fields. This was due largely to drilling through the upper less productive strata, with no provision for shutting off the water, and into the lower and most prolific sands which were capable of yielding flowing wells. (2) Water trouble since the revolution. This is due to the decline of oil production and a marked decrease in the number of producing wells.

Not all areas in the Baku district have been affected to the same extent by the penetration of water. The Binagady and Surakhany areas have been affected comparatively little. Water trouble in the Sviatoy Island field has so far not been discussed. In the Grozny field a temporary stoppage of production has resulted in water trouble in certain areas, and the encroachment of water is also noticeable in the Novo-Grozny field, especially in the eastern part. This last, however, is mainly due to failure to completely shut off the water in a number of wells prior to the nationalization of oil fields.

A resolution adopted by the First All-Russian Congress of Oil Operators concerning the invasion by water of the Baku and Grozny producing areas is appended to this paper. It also contains a résumé of the transactions of the Geological Section with regard to the question of water trouble in the principal Russian oil fields.

G. K. DRACH

Handbook of the Petroleum Industry. By DAVID T. DAY, Editor in Chief. New York: John Wiley and Sons Inc. 2 volumes, 1970 pages, 6 by 9 inches. Price $15.00.

Day's *Handbook of the Petroleum Industry* is the first compilation of facts designed to serve as a comprehensive and authoritative reference on the many interlocking branches of the petroleum industry. This compilation, to be of greatest value, had to be prepared by a recognized authority, and, since no one is an authority on all phases of the industry, Mr. Day called on a number of experts to prepare chapters on their specialties. As a result, sixteen distinct subjects are treated by as many writers. It is inevitable that the different chapters prepared in this way vary in their degree of excellence and the work is not perfectly balanced, but it is much more important that a reference work for scientists should be authoritative than that it should be a literary gem.

A perfect handbook dealing with any industry should be an assemblage of facts, figures, and rules peculiar and *essential* to the industry, supplemented by a discriminating selection of information from other industries and sciences. Day's handbook is not a perfect work; it is the first edition of the first effort to meet the unquestionable need of the petroleum industry for a work of this type, and no first edition is without shortcomings, but it is a noteworthy addition

to the literature on the petroleum industry, and the harassed engineer who has been searching through files of technical magazines, stacks of separates, and shelves loaded with government bulletins, works on oil geology, production, refining, transportation and what not, for the answer to some particular question will joyfully welcome this work in which he can easily find concise and understandable answers to many of the problems that vex him.

The reviewer has no desire to pose as a technical expert. His knowledge of many of the subjects is of a very general nature, and the handbook is discussed solely on its apparent value as a reference book for the petroleum geologist, who has a valid interest in all the subjects presented, for he may at any time be called to do or direct work that will demand an acquaintance with theory and technique pertaining to some of the topics discussed in the handbook. Yet petroleum geology alone is so broad that it is almost hopeless for him to aspire to be expert in every branch of it, and it is therefore clearly unreasonable to expect him to be expert also in all other branches of the industry. If he cannot carry the necessary information in his head, he should have it available in some other manner, and a compilation in handbook form should therefore be particularly welcome.

The volumes are rather bulky to be called a handbook. Some economy in size could have been attained by using smaller type, particularly in the tables, and much more could have been gained by using fewer illustrations. Certain of the sections could undoubtedly have been condensed somewhat without losing much that was essential. For library volumes, however, the size is no drawback, and, whether, they be termed a handbook or a treatise on the petroleum industry, their worth is little affected by the possible inappropriateness of the name.

The first chapter, "Occurrence of Petroleum," by Frederic G. Clapp, consulting geologist, is in part a compilation and revision of his earlier writings on the same subject. He discusses conditions essential to the occurrence of oil and describes surface indications briefly but thoroughly, concluding by pointing out that "surface indications are not essential to the existence of an oil field" and that even "in many cases where asphaltic deposits are very old geologically, the petroleum seems to have completely disappeared." This is followed by consideration of "Relation of Petroleum Occurrence to Metamorphism" which, in the opinion of the reviewer, is much too short, for the subject is vital and all too little understood. However, references are given which compensate, to some extent, for the summary treatment.

The presentation of "Relation of Petroleum Occurrence to Stratigraphy" is excellently designed for quick reference. Ages of the productive strata in the important oil-yielding districts of North America are tabulated, and productivity of various geologic systems and some geologic series are tersely given, with specific mention of some of the most important producing horizons. Treatment of the Appalachian district is particularly good and the discussion

of conditions in parts of the Mid-continent and Gulf Coast fields suffer by contrast. Producers in the Gulf Coast fields will be surprised to learn that all Texas oil is obtained from pre-Tertiary beds and that oil-fields which produce from the Oligocene "are mainly confined to California," and stratigraphers will be unhappy when they see the Dakota sandstone classified as Lower Cretaceous. On the other hand, statements regarding the possible productivity of certain regions show optimistic breadth, which is to be highly commended.

The treatment of "Relation of Petroleum Occurrence to Geologic Structure" is an analysis of the apparent relation between geologic structure as it is revealed by outcrops and the occurrence of oil, and differs little from previous discussions by Mr. Clapp covering this topic.

More than half the chapter is given over to a discussion of oil fields in the different states of the Union and in foreign countries. The locations of oil and gas fields and pipe lines are shown by state and regional maps, which are very helpful but which could be improved by the introduction of system into the numbering scheme to facilitate the location of any particular pool. Failure to give the horizontal scale of most of the maps is a serious oversight.

The reader will search this section in vain for statements of the gravities and chemical characters of oils from different districts. These data will be found in the chapter on "Characteristics of Petroleum." The outputs of the various districts are given in the chapter on "Statistics of Petroleum and Natural Gas Production."

"Field Methods in Petroleum Goelogy" are described by Frederic H. Lahee, chief geologist of the Sun Company. Many of these data appeared in the same author's handbook on *Field Geology* which was reviewed in the *Bulletin of the American Association of Petroleum Geologists* by Julian D. Sears. The author sticks to his subject without digressing to theorize or to furnish information on subsurface work, office methods, and other supplements of field work. In fact, the chapter might more appropriately be headed "Mapping Methods" than "Field Methods," for little space is given to observations other than those the geologist will incorporate on his map. As a manual of instruction for the novice it is incomplete, for it does not give the technique of making many of the observations which it describes. Parts of it, such as the descriptions of instruments, are plainly designed for the beginner, but even in these descriptions helpful details might be added, such as descriptions, preferably illustrated, of different methods of taking sights and reading angles with Brunton and Gurley type compasses; the method of measuring a stratigraphic section where the beds are dipping, using the Brunton compass or Abney level; the measurement of a stratigraphic section in dipping beds with a Locke level by making the measurement along strike; reasons for or against using a Jacob staff in hand-level work; and the various methods of making distance readings with stadia when the rod is so far away that it cannot be simultaneously intercepted by two of the horizontal hairs in the alidade.

The description of the barometric method is particularly good and the entire chapter is notably free from erroneous statements. All those noted by the reviewer are in the discussion of methods of planetable operation. The description of the "step method" for measuring vertical distances fails to state that the *middle* hair should be moved to take the position of the top hair for the first step. Except for this omission the description is correct. Also, the statement that one revolution of the Stebinger drum "raises or lowers the telescope one interval" implies an accuracy in milling screws which has not been attained, for it is seldom that the telescopes of two alidades are moved through the same vertical arc by one revolution of the drum.

The chapters on "Oil-Field Development," by the late Louis C. Sands, on "Statistics of Petroleum and Natural Gas Production," by Anne B. Coons, and on "Transportation of Petroleum Products," by Forrest M. Towl, which follow in the order given, deal with phrases of the petroleum industry frequently touched by the oil geologist. The reviewer would not presume to discuss these chapters critically. To him they are an assemblage of extremely helpful information, and if they have shortcomings, in so far as their technical data are concerned, he was too inexpert to detect them.

The chapter on "Characteristics of Petroleum," by David T. Day, which tabulates and describes characteristics and properties very comprehensively, seems to the reviewer well suited to meet most of the needs of the average petroleum geologist, and with the supplementary information in the excellent chapter on "Testing Methods," by T. G. Delbridge, of the Atlantic Refining Co., makes a very satisfactory reference.

"Natural Gas Gasoline" is discussed by H. C. Cooper, chief engineer of the Hope Natural Gas Co., who presents simply and understandably the methods for separating gasoline from natural gas, gives methods for testing gas for gasoline content, describes the construction of gasoline extraction plants, etc. This chapter can be recommended to both layman and geologist, for the arrangement is good, the language is simple, and illustrations and examples clarify details that might otherwise be troublesome.

A chapter on "Asphalt," by Reginald G. Smith, of the Standard Oil Co. of California, contains statistics of asphalt production and consumption and tabulations of occurrences of native asphalts as well as descriptions of methods of refining and testing asphalt, its uses, and many other data. The table of asphalt occurrences outside the United States is particularly interesting, as it indicates the possible occurrence of oil in many regions that are not now producing. This chapter could be improved in both arrangement and presentation, for the author apparently failed to realize that his familiarity with terminology and processes would not be shared by many of his readers, and he also has a tendency to mention requisites without making a clear statement of how they may be supplied.

"Oil Shale" is discussed by David Eliot Day and A. H. Heller. Oil shales are classified, theories of origin are outlined, and occurrence, sampling, testing,

and mining of oil shales are discussed. Tabulations of yields of oil, ammonium sulphate, and fixed gas, of oil gravities, etc., add to the value of the chapter. The definition of oil shales as "All rocks which . . . . may be petrographically classed as shale and which will yield volatile hydrocarbons by some method of treatment" will not meet unqualified approval.

A chapter on "Refining" takes up the first 426 pages of Volume II. The first 318 pages deal with selection of sites, design of plant, and specifications for equipment, and are of doubtful value for the geologist, for only a specialist on refinery construction is liable to have occasion to use these data. The remaining part of the chapter which discusses management, refining processes, refinery fires, and yields and costs, should be more useful for the geologist, although parts of it are difficult to follow unless one is well versed in the terminology used.

The discussion of "Cracking Processes," by Roland B. Day, is, to the reviewer, one of the most interesting in the books, although the type of information is qualitative, not quantitative. It is easy to read and understand, but it may be criticized because it does not furnish details nor give data that will permit judgment of the relative excellence of different processes.

"The Use of Fuel Oils" is discussed by the late W. N. Best, consulting engineer. The treatment is excellent and both expert and novice may profit by studying this chapter. Much of the story is told by diagram and illustration, but there is enough text to make these clear. The superiority of oil over coal for many purposes, and the manner in which it should be used, are pointed out without any attempt to belittle the suitability of coal for many uses.

The chapter on "Internal Combustion Petroleum Engines," by Arthur H. Goldingham, presents certain essential principles of thermodynamics, describes many types of internal combustion engines, gives data on costs, fuel consumption, relative merits of steam and oil engines, and other features of interest. It also gives many references in this differing from most of the authors who have contributed to the handbook.

The treatment of "Lubrication," by John D. Gill, is considered by the reviewer more nearly ideal for handbook purposes than any other section of the handbook. No words are wasted but essentials are not slighted. It is clear and understandable and the theory is clarified by the use of examples. Furthermore, he gives sources for many of his statements of facts, formulas, etc., and a good list of references.

The final chapter is on pipe standards and the use of pipe, by F. N. Speller, of the National Tube Co., Methods of manufacture are described, principles of pipe-threading are given, corrosion is very briefly discussed, and numerous tables of weights and dimensions of pipes, collapsing pressures, etc., are given. Many data that would naturally fall under this heading may be found in the discussions of "Oil-field Development" and "Transportation of Petroleum Products," but if one is familiar with other parts of the handbook the treatment in this chapter should be very satisfactory.

In the back of the book there are seventy-one pages of tables. This section could to advantage be amplified by giving tables of logarithms, trigonometric functions, more foreign weights and measures, and other data. There is also a helpful list of currrent sources of petroleum information which gives the names of some thirty-five such sources, including government bureaus, technical journals, official publications of scientific societies, etc. The list would be better if addresses as well as names were given and if it were longer. A comprehensive list of books on petroleum, printed in English, is also given. Finally there is an eightysix-page glossary of terms in common use in the petroleum industry. The index is remarkably well prepared, and an excellent feature is that the full index for both volumes is printed in each. This is also true for the list of chapters. The book-making leaves little to be desired.

K. C. HEALD

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[1] Published by permission of acting director, United States Geological Survey.

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BERTRAND L. JOHNSON[1]

[1] Compiled with the assistance of Miss L. M. Jones.

THE ASSOCIATION ROUND TABLE

ANNUAL MEETING OF THE ASSOCIATION

The next annual meeting of the Association will be held in Houston, Texas, March 20 to 23, 1924. Begin to lay your plans now so there will be no possibility of your missing it. The Gulf Coast men have been active in every meeting of the Association and have contributed much to their success. Now they promise us one bigger and better than ever. Let's go!

REGIONAL DIRECTORS

Chester W. Washburne, 2 Rector Street, New York City, has been appointed Regional Director for the Eastern Region.

Cassius A. Fisher, 711 First National Bank Building, Denver, Colo., has been appointed Regional Director for the Rocky Mountain Region.

AT HOME AND ABROAD

JOHN M. HERALD has resigned his position as head geologist of the Roxana Petroleum Corporation after having been on the geological staff of this Dutch Schell subsidiary for more than eight years. He and his brother, FRANK A. HERALD, have formed a partnership for the purpose of doing a consulting business. The partnership, which will operate under the name of Herald Brothers, has established an office at 303 Cosden Building, Tulsa, Oklahoma.

DOUGLAS R. SEMMES, assistant chief geologist of the Mexican Eagle Oil Co., left Tampico early in July to spend several months at the Hague.

PROFESSOR GALLOWAY, of the Geological Department of Columbia University, is engaged for the summer in micro-paleontological work for the International Petroleum Co. at Tampico, Mexico.

JOSEPH T. SINGEWALD, of the Geological Department of Johns Hopkins University, is spending the summer in Mexico for the Transcontinental Petroleum Co.

HOMER A. NOBLE has recently joined the geological staff of the Marland Oil Company of Mexico, with headquarters at Panuco, Veracruz, Mexico. He is engaged in micro-paleontological work.

JOHN G. BARTRAM has resigned his position as district geologist for the Roxana Petroleum Corporation to accept a position with the Midwest Refining Company at Casper, Wyoming.

ESTHER FRANZ, who has been an office geologist for the Roxana Petroleum Corporation for several years, has resigned.

WALTER M. SMALL is now chief geologist for the Cia Petrolera del Agui, Tampico, Mexico.

In the consolidation of the Corona and Aguila Companies, Mexican subsidiaries of Dutch Schell, the geological departments have been placed under the direction of A. H. NOBLE, formerly chief geologist for the Corona. DOUGLAS R. SEMMES, formerly assistant chief geologist for the Aguila and JOHN MUIR, formerly assistant chief geologist for the Corona, retain the same positions in the consolidation. PAUL WEAVER, formerly chief geologist for the Aguila, is now in charge of the Dutch Schell geological work in the Isthmus of Tehuantepec, where he is assisted by about fifty geologists.

HENRY HINDS is in Venezuela for the Buckley Petroleum Co.

F. H. LAHEE, chief geologist of the Sun Oil Co., is temporarily engaged in foreign work.

FRANK A. HERALD has resigned from his position on the executive staff of Cia. Petrolera del Agwi, Tampico, Mexico, and is now established in a consulting business with his brother, JOHN M. HERALD, at 303 Cosden Building, Tulsa, Oklahoma.

DR. C. E. DECKER, secretary-treasurer of the Association, gave the course in geology at the Colorado Teachers College summer school in Estes Park during August. During this work he made a number of new observations, some of occurrences previously unnoted, some involving modifications of previously published opinions, regarding geologic features of the Park region. Those of us who have had opportunity to discuss these observations with Dr. Decker hope that he will put them in print in the near future.

WILLARD CUTLER is working out the geology of the various California oil fields in the interests of the McKanna Syndicate.

PROFESSOR PAUL P. GOUDKOFF, of the Tomsk, Siberia, Institute of Technology, is also with the McKanna Syndicate as a geologist. Professor Goudkoff first came to America to attend the disarmament conference in Washington in charge of the delegation sent by the Maritime Chamber of Commerce from Vladivostok.

RALPH O. RHOADES and W. H. THRALLS have formed a partnership to carry on geological examinations, and will have their offices for the present at 422 Union National Bank Building, Wichita, Kansas. Mr. Thralls has been working independently with his office at this address since the first of this year. Mr. Rhoades was formerly connected with Carl H. Beal in San Francisco and has only recently returned from an eight months' investigation of the petroleum possibilities of Egypt. This work was carried on by Americans backed by Egyptian capital.

LEE HAGER has returned from an extensive trip in the Orient.

W. H. GEIS and M. J. HOPKINS have returned to Casper from a trip through the California fields.

ERNEST MARQUARDT spent a large part of the summer on a trip to Alaska to inspect the Cold Bay properties of the Alaska Oil Co., a subsidiary of the New York Oil Co., of which he is vice-president.

KENNETH B. NOWELS, who has been with the Midwest Refining Co. at Salt Creek for the past three years, has been appointed assistant petroleum engineer for the United States Bureau of Mines and will remain in the Salt Creek field for the present.

H. W. BELL, formerly of the United States Bureau of Mines, has been appointed supervisor of the Mineral Division of the Department of Conservation of the State of Louisiana, to fill the vacancy left by the resignation of BEN K. STROUD.

FRANK A. HERALD and JOHN M. HERALD have formed a partnership to be known as Herald Brothers, and have opened an office for general consulting at 303 Cosden Building, Tulsa.

E. B. EMRICK, formerly with the Carter Oil Co. in the Rocky Mountain states, is now employed as valuation engineer, Oil and Gas Section, Natural Resource Division of the Income Tax Unit, Treasury Department. His address is 302 Klingle Mansions, Washington, D.C.

ROY HOLLOMAN resigned September 1 from the Minerals Division of the Louisiana State Conservation Commission at Shreveport to join the geological department of the Ohio Oil Co., working in north Louisiana and south Arkansas.

HENRY S. RADE recently resigned from the geological staff of the Arkansas Natural Gas Co., Shreveport, Louisiana, to take a position as geologist with the Rycade Oil Corporation with headquarters at Houston, Texas.

W. C. SPOONER, chief geologist for the Arkansas Natural Gas Co. at Shreveport, Louisiana, returned to Shreveport in September after spending the summer in work for the company in Montana and adjoining territory.